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Application of the TerreSIM Model to a Training Area Landscape at Fort Bliss, TX

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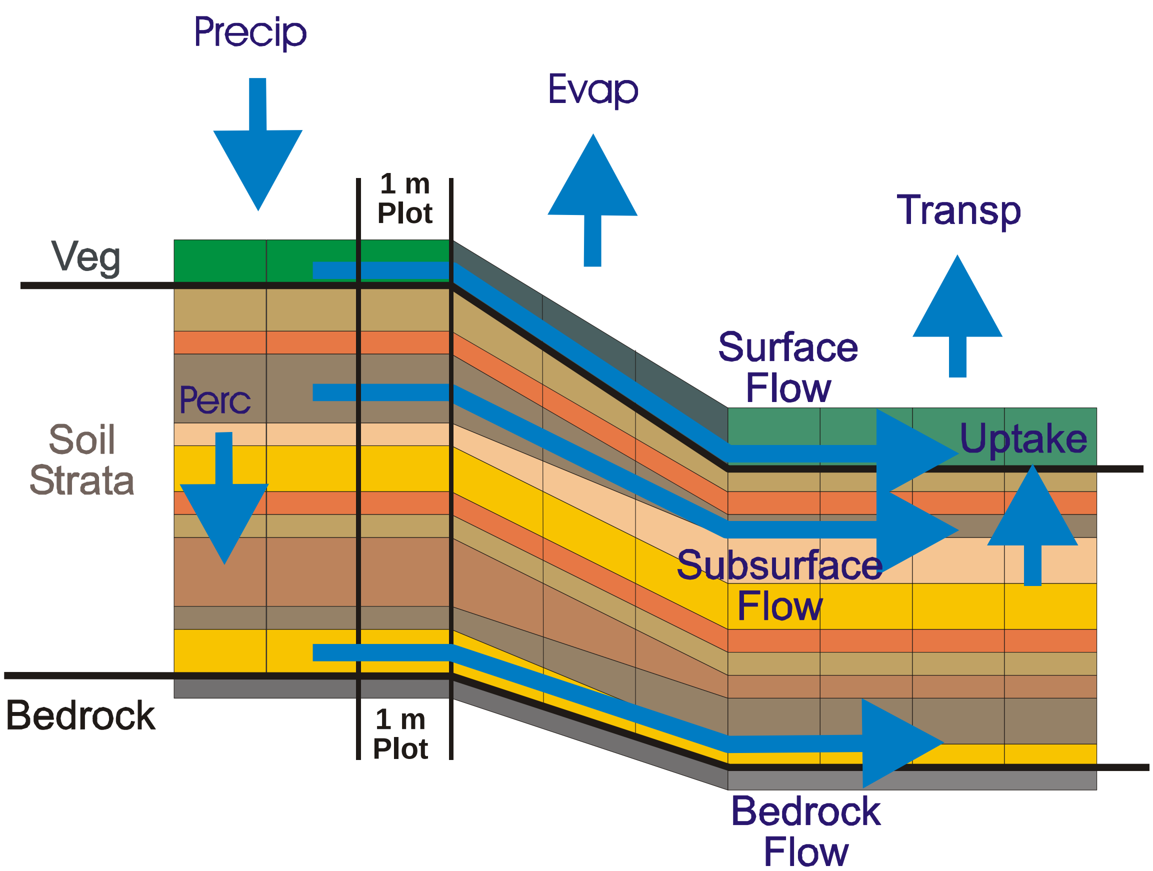

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ABSTRACT: The Terrestrial Ecosystem Simulation Model (TerreSIM) is a computer simulation model designed to be a useful evaluation and planning tool for investigating ecological responses over time to a wide variety of natural and anthropogenic stressors on spatial scales ranging from small plots to large landscapes and watersheds. TerreSIM is the next generation of modeling efforts at MFG, Inc, built upon general principles of ecology. This document presents the results of an application of the TerreSIM model to a 94 km^2 training area landscape in the north central part of Fort Bliss. Results of these simulations indicate that fire, cattle grazing, and military training all affect vegetation dynamics on this landscape, but that the relative importance of each factor is quite different. Model simulations indicate that the landscape can support moderate grazing by cattle and military training for at least 20 years, provided that at least average precipitation is received. TerreSIM provides the tool for Fort Bliss land managers to develop appropriate management options under changing climatic, pyric, and successional conditions.

Executive Summary

A training area located in the McGregor Range was selected by Fort Bliss personnel to be included in the initial application of TerreSIM (©2003 MFG, Inc.). This 94 km^2 landscape was spatially represented in the model by 104,811 cells, each cell representing a 30 m x 30 m area. The model included 11 plant communities (including disturbance types), 6 topographic units, and 14 plant species, along with several management scenarios (cattle grazing, prescribed fire, movement of livestock watering tanks, Patriot missile training, bombing training, vehicle training (four types), and bivouacking). Natural ecological stressors included precipitation fluctuations, nitrogen availability, shrub invasion, natural fires, intra- and interspecific competition, ecological succession, and natural herbivory.

Twenty-year simulations were conducted to evaluate the effects of various combinations of the management scenarios on vegetation dynamics and watershed yield, under varying levels of the natural stressors. Of particular interest was the comparison of the relative impacts of military training and livestock grazing.

Results of these simulations indicate that fire, cattle grazing, and military training all affect vegetation dynamics on this landscape, but that the relative importance of each factor is quite different. In the absence of grazing or training, fire is an important factor maintaining the grassland component of this landscape. In the absence of fire, shrubs increase 35 percent over a 20-year period and grasses decrease by 23 percent, under an average precipitation regime. Cattle grazing, at both light and moderate stocking rates, increases the ecological effect of lack of fire. Shrubs, especially creosotebush, increase further and grasses, especially black grama, decrease further. The use of prescribed fire combined with moderate cattle grazing largely eliminates the increase in shrubs associated with cattle grazing, but the combination of fire and continuous grazing reduces the production of grasses even more than grazing without fire. The area should be rested from grazing for at least 1 year, and preferably longer, following a fire.

Military training had a similar but lesser impact on the landscape as did cattle grazing. Of the four types of training simulated, combined wheeled- and tracked-vehicle training had the greatest impact, followed by wheeled vehicles only, Patriot missile training, and bombing, in that order.

These model simulations indicate that the landscape can support moderate grazing by cattle and military training for at least 20 years, provided that at least average precipitation is received. However, the combination of grazing and training will result in a greater increase in shrubs and a greater decrease in grasses than without grazing and training. If grazing were eliminated, the landscape would be impacted less than if training were eliminated. If both management options are continued, adjustments in intensity and seasonality of each may need to be made on a regular basis to adjust for changes in ecological effects of natural stressors, especially drought and fire regimes. TerreSIM provides the tool that allows Fort Bliss land managers the ability to develop the appropriate management options under changing climatic, pyric, and successional conditions.

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Preface

This study was conducted for Department of the Army under project number 622720A896, "Base Facility Environmental Quality"; Work Unit 008B3X. The technical monitor was Bill Woodson, Office of the Director of Environmental Programs (DAIM-ED).

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division, Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Jeffrey S. Fehmi. Part of this work was done by MFG, Inc., Fort Collins, CO under DACA 88-99-D-0004-0009, Task 3. The technical editor was Linda Goersch, Information Technology Laboratory. Alan Anderson is Chief, CN-N, and L. Michael Golish is Acting Chief, CN. The associated Technical Director was William D. Severinghaus, CVT. The Acting Director of CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

The Terrestrial Ecosystem Simulation Model – TerreSIM (©2003 MFG, Inc.) is a personal computer (PC)-based, mechanistic, spatially explicit, and temporally dynamic simulation model developed as a successor to the Ecological Dynamics Simulation (EDYS) Model (Childress and McLendon 1999; Childress et al. 1999a, 1999b). TerreSIM simulates changes in soil, water, plant, animal, and landscape components resulting from natural and anthropogenic ecological stressors. It can be applied to a wide variety of ecosystems, management scenarios, and disturbance regimes.

The TerreSIM model consists of Climate, Soil, Hydrologic, Plant, Animal, Stressor, Spatial, Landscape, and Management modules. Climatic inputs can be historical or stochastically generated, or a combination of both. The Soil Module is divided into layers (horizons, subhorizons, or artificial layers), of which the number, depth, and physical and chemical characteristics are site-specific for each application. The Hydrologic Module provides for infiltration and water movement through the soil profile, surface movement of water, surface erosion, sediment movement, subsurface movement of water, and changes in water quality. The Plant Module includes above- and belowground components for each species included in the application. Plant species are defined by the user. Plant growth is dynamic in relation to plant components (e.g., roots, trunk, stems, leaves, seeds, and standing dead), season, resource requirements (e.g., water, nutrients, sunlight), and stressors (e.g., herbivory, competition, fire, trampling, chemical contaminants). The Animal Module consists of basic population parameters and diet attributes (e.g., preferences, utilization potential, competitive success) for each species (e.g., insects, rodent, native ungulates, livestock). The Stressor Module includes drought, nutrient availability, fire, herbivory, trampling (e.g., foot, vehicle), contaminants, shading, and competition (e.g., soil moisture, nutrients, food). The Spatial Module allows growth of individual plants (e.g., trees) and distribution patterns (e.g., colonies, fire patterns, soil heterogeneity) to be explicitly represented in the simulations. The Landscape Module allows for multi-scale simulations including: fine scale (1 m^2 or smaller), patches (e.g., 100 m^2), communities (e.g., 1–10 hectares), and landscapes and watersheds (1 km^2 and larger). Time intervals vary from day (e.g., precipitation events, plant water demand, fire, herbivory), to month (e.g., species composition), to year and longer (e.g., climatic cycles).

The U.S. Army Corps of Engineers has supported the application of the model to various military land management scenarios. This report presents the results of an application to a 94 km^2 training area at Fort Bliss, in west Texas and southern New Mexico, funded by the U.S. Army Engineer Research and Development Center (ERDC). Twenty-year simulations were conducted to evaluate the relative impacts of nine management scenarios on vegetation dynamics, watershed yield, and livestock diets. Of particular interest was the comparison of the relative impacts of military training and livestock grazing. This report presents details of the Fort Bliss application of TerreSIM, including parameterization values, users manual, source references, and simulation results.

Background

The Integrated Training Area Management (ITAM) program is the principal program used by the Army to manage its training lands. A component of ITAM, Land Condition Trend Analysis (LCTA) provides installation land managers with an estimate of the condition of their training lands as well as trends occurring in those natural resources. Office of the Deputy Chief of Staff for Operations and Plans (Army) or ODCSOPS, currently responsible for the ITAM program, has initiated actions to improve the value of LCTA data to the day-to-day management of the Army's natural resource assets within the context of ITAM. One of these initiatives is to develop methods that can link the costs associated with maintaining training lands to the actual level of training activity imposed on the landscape and the resulting trend in its condition. Over the last two decades, these efforts have enhanced the Army's position as a good steward of the land it administers and the land's associated natural resources.

Despite these efforts, however, increasing public concern regarding the environment and military operations continues to generate new legal and regulatory restrictions on training land usage. In particular, impacts on soil stability, the integrity of training land vegetation, threatened and endangered species habitat, and water quality are among the major concerns. The traditional approach to addressing these concerns has been to gather the data necessary to make a judgment regarding the condition and trends in these public resources. The high costs associated with the acquisition of these data, however, coupled with those required for the subsequent design and implementation of restoration or rehabilitation efforts, are often prohibitive until the issue becomes a regulatory or compliance problem for the Army. Therefore, training land management has become a process of managing a prioritized level of problems rather than one designed to be preventative in nature.

The Deputy Under Secretary of Defense for Environmental Security has initiated an effort to help training land managers deal with this situation by supporting the use of modeling and simulation technologies within the context of ecosystem management. The idea was to use readily available data in conjunction with ecological simulation modeling and knowledge of management-oriented ecological thresholds to predict the outcomes of various training land usage scenarios. This approach reduces the cost of data acquisition by limiting required data to only those needed to develop a sound a priori decision or management strategy.

Research in the area of ecological simulation modeling had been limited until a few years ago. The development of EDYS and a few other dynamic simulation modeling software packages in the middle to late 1990s laid the groundwork for today's efforts. In Fiscal Year (FY) 1995, the U.S. Army Construction Engineering Laboratory (CERL), now under the U.S. Army ERDC umbrella, initiated an applied research project to develop a mechanistic-based ecological dynamics simulation model. The plan was to incorporate current knowledge of military impacts and management scenarios on training lands into the model. This approach would enable prediction of training land carrying capacity and facilitate linking the cost of training to land and resource maintenance. Initial efforts in evaluating land management simulation models that were available in the public domain and adaptable for this purpose resulted in one or more of the following conclusions: (1) the available models were overly general and of little practical value in the evaluation of specific management scenarios, (2) other models were overly specific and therefore limited to one or a few sites, and (3) some models were very complex and required extensive calibration with site-specific data that were not available, or the systems they evaluated were limited and did not run the full array of ecologically important factors.

There was, however, an existing private sector simulation model that did not suffer from the above constraints (Childress et al. 1999). Therefore, CERL researchers determined the most cost effective way to pursue this research effort was to partner with the private sector and several key installations to develop applications of the existing ecological simulation modeling technology. The core model was generally applicable Army-wide but could easily be made applicable to a particular installation with a minimum number of site-specific data requirements. That collaboration produced the EDYS model and laid the foundation for TerreSIM, the next generation of ecological modeling software.

Objective

TerreSIM was developed with specific objectives:

1. Develop a quantitative vegetation dynamics model that is adaptable and user-friendly, while remaining temporally and spatially explicit enough to lend itself to practical land management decisions.
2. Make the software flexible enough to simulate most terrestrial ecosystems and robust enough to simulate ecological dynamics on a landscape scale, assimilating stressors placed on the environment by a suite of military training activities. It should also be easily calibrated for site-specific applications using data from the literature and/or currently available from the installation's own research and monitoring efforts.
3. Build the simulation model to stand alone as a PC-based application that can be easily run and manipulated by the end user in a geographic information system environment.

Approach

The TerreSIM model is designed to be a stand-alone application that land managers can use to assist them in the decision-making process. Once installed on the end user's computer, the TerreSIM software suite is linked internally to the software's database, which contains the model run parameters. This database can be customized to include site-specific ecosystem and species data. The database is initialized with a set of default parameters developed by MFG ecologists, however, and the application will run right "out of the box" using the preliminary settings. These data are consistent with site conditions and the species found at the simulation location, but may also be modified by the user and any of the model's run parameters can be manipulated as site conditions change or new and better data become available.

Mode of Technology Transfer

The TerreSIM model described in this report has been developed for the Army, Department of Defense (DOD), and other Federal and private land managers. The model has been produced as a stand-alone PC-based program that will serve as a tool for natural resource managers in the decision-making process. It may also be linked with other appropriate simulation technologies, as well as assessment and planning environments; therefore, TerreSIM can be leveraged with other Federal agencies.

This report will be made accessible through the World Wide Web (WWW) at URL:
http://www.cecer.army.mil

2 General Model Software Description

The TerreSIM model is a stand-alone application that land managers operate to assist in the decision-making process. The TerreSIM software suite is deployed on the end user's PC. The model is internally linked to the TerreSIM database, which contains the model run parameters, and can be customized to include detailed literature data-specific to the ecosystem and species at the related site. The database is deployed with default parameters developed by MFG ecologists to be consistent with site conditions and the species found at the application location. The user can modify any of the model's run parameters to be comparable with changing conditions at the site, or use the default parameters supplied with the application.

The user can view and modify not only the parameters but the spatial inputs as well. TerreSIM operates spatially on a fixed, predefined area of the landscape selected at the initial application setup, using a grid structure. The individual cell sizes in the spatial grid are a fixed size, as defined at the initial application setup. These cells can be as small as 1 m^2, or much larger (e.g., 30 ha). Within this fixed area, management boundaries, roads, plant communities, fence lines, and any other unique areas to be modeled can be defined and modified to reflect changing site conditions. The software suite contains the TerreSIM Map component, which allows the user to view and modify the model spatial data. The Map component also will display any shapefiles or images available for the site.

The management options available in the Fort Bliss application of the TerreSIM model include fire, herbivory, Patriot missile, bombing, vehicle training, and bivouac. At the start of each run, the user can select the various controls available for these management options, including spatial initiation, start date, frequency, and any other values specific to the management activity type (e.g., intensity of grazing, type of bomb used, etc).

TerreSIM is designed to simultaneously simulate ecosystem dynamics at three different spatial scales: plots, communities, and landscapes. This approach allows adequate representation of ecological processes that operate at different spatial and temporal scales. Because the model uses mechanistic representations of each process at the most appropriate scale, linkages among different components of the community, ecosystem, and landscape can be projected with reasonable confidence.

The Plot Module simulates ecological mechanisms and dynamics at the small scale (1-m^2 to 400 m^2). Most of the processes in the model related to plants (e.g., growth, water and nutrient uptake, and competition) and soils (e.g., water and nutrient transport through the profile, decomposition) are implemented in this module (Figure 1). This Module comprises a number of submodules, including Climate, Soil, Hydrologic, Plant, and Animals. Climatic inputs, primarily precipitation and evapotranspiration potential, are (1) based on historical data, (2) stochastically generated, or (3) some combination of both.

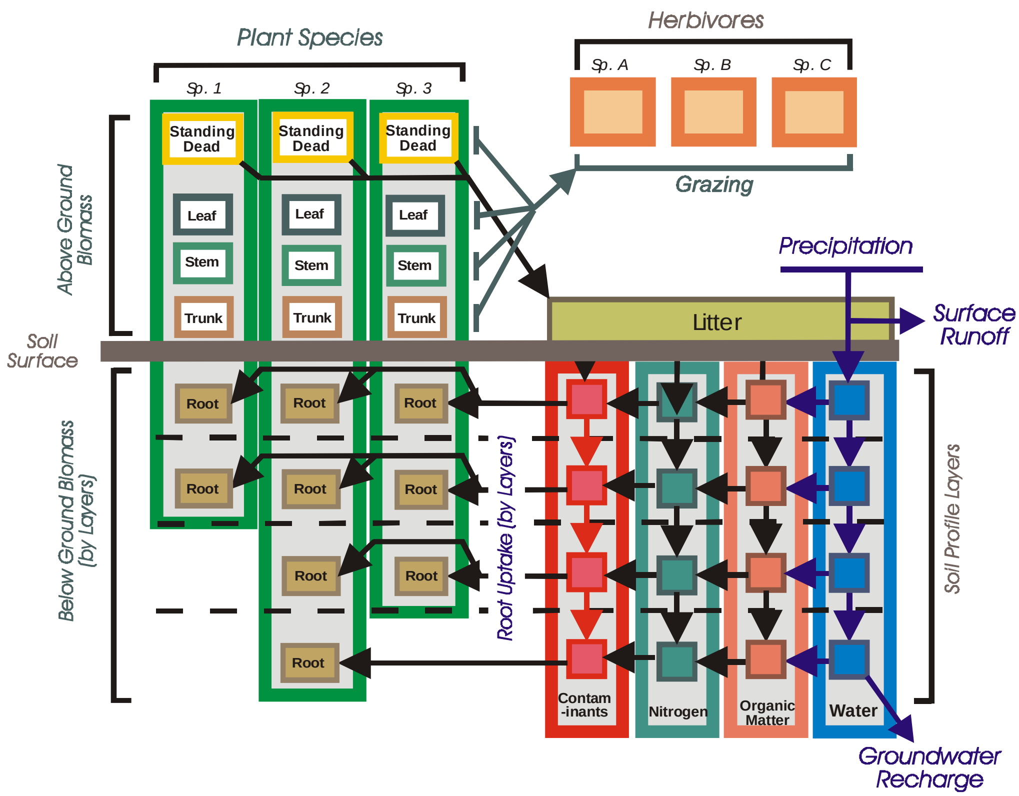

Figure 1. Model plot-level structure.

The Soil Module represents the soil component by partitioning the profile into different layers (horizons, subhorizons, or artificial layers). This representation incorporates the vertical depth, water content and holding capacity, nitrogen content, organic matter content, microbial activity, decomposition, and contaminant content and activity for each layer.

The Hydrologic Module simulates small-scale precipitation dynamics, including interception by aboveground plant biomass, surface runoff, erosion and sediment mobilization, infiltration of water through the profile, mobilization and transport of nitrogen, organic matter, and contaminants, and subsurface export of water out of the profile.

The Plant Module represents the dynamics of above- and belowground components for each major plant species. Plant growth is simulated for each component (e.g., roots, trunk, stems, leaves, seeds, and standing dead), relative to season, resource requirements (e.g., water, nutrients, sunlight), and stressors (e.g., herbivory, competition, fire, trampling, chemical contaminants). The Animal Module consists of basic population parameters and diet attributes (e.g., preferences, utilization potential, competitive success) for each specified species (e.g., insects, rodent, native ungulates, livestock).

Different plots are represented as cells in the Community Grid. The Community Module focuses on spatial patterns and dynamics from the scale of the patch (400 m^2) to the community (1–10 hectares). These patterns and dynamics include spatial heterogeneity in soils, plants, and stressors among plots within the community, stressors such as fire propagation, grazing, and lateral flow of surface and subsurface water and materials, and important spatial patterns such as vegetation cover, habitats, and topography.

In an analogous manner, communities are the basic units in the Landscape Grid. This largest scale module focuses on ecological processes operating at large spatial scales (1-km^2 and larger). Processes include fire initiation regimes, climatic regimes, watershed-level water movement and transport of materials, and management practices such as training scheduling, grazing operations, and weed control.

Simulation Outputs

Each simulation run of the TerreSIM model produces extensive data for all state variables (e.g., plant biomasses, water and nutrient contents of soils, total surface runoff) and processes (e.g., water and nutrient transport and balances, plant production). These data are stored in a series of text tables, typically on a monthly basis. Most of these data are also presented in graphical displays at the end of the simulation run. These data are required for accurately testing and calibrating the application for particular communities and sites. In addition, these data can be sent in “real time” to other models running simultaneously.

Hydrological Dynamics in TerreSIM

An important component of TerreSIM at all scales is hydrological dynamics. The Plot Module focuses primarily on one-dimensional movement of water up and down in the soil profile. Precipitation events deliver water to each plot, which then percolates down into different layers in the profile. Evaporation removes water from the top horizons, and uptake by plant roots in each horizon is transpired as plants grow. The Community and Landscape Grids allow explicit representation of transport of water among different cells (Figure 2). This allows calculation of surface runoff, subsurface export, and transport of sediment, nutrients, and contaminants across the landscape.

Among the various outputs produced in each TerreSIM simulation run are tables describing water pools and dynamics as well as summary graphical displays of total landscape runoff and export. These outputs allow projection of the effects of different climatic regimes, ecological stressors, vegetation dynamics, and management practices on surface and subsurface water quantity and quality.

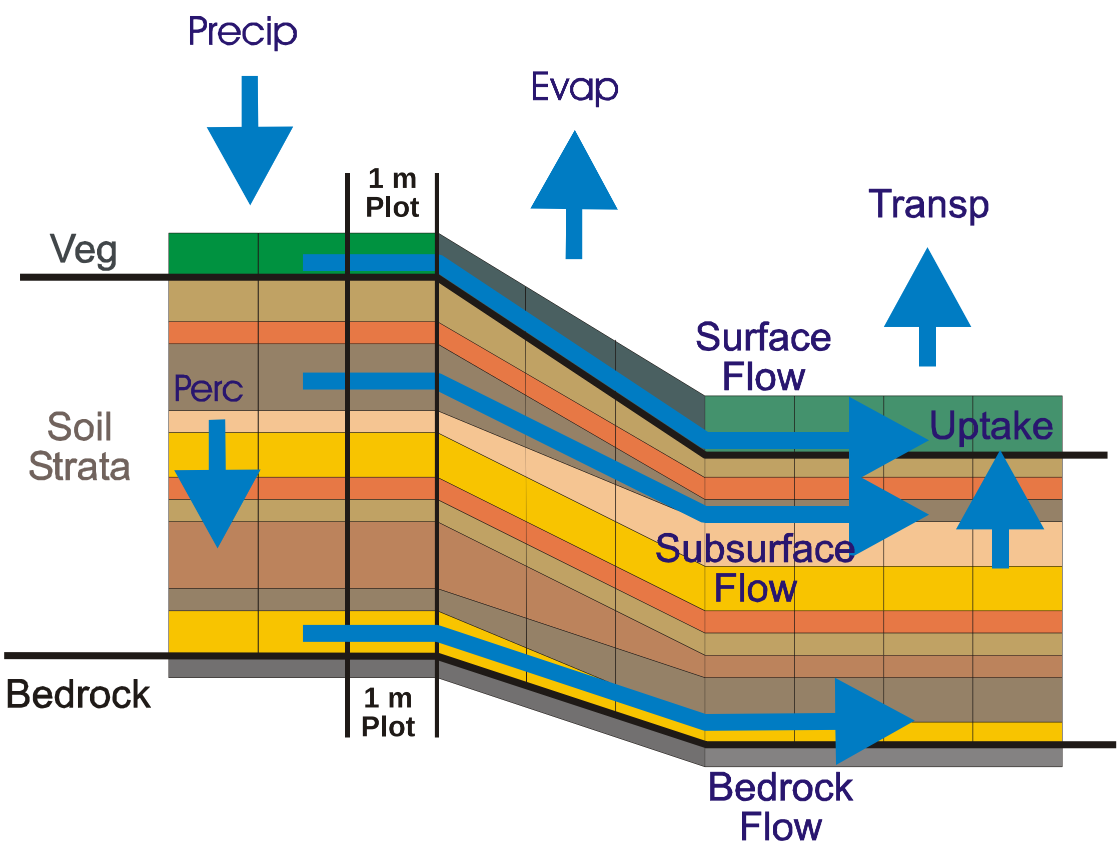

Figure 2. Hydrological dynamics in the landscape module.

3 Fort Bliss Landscape

Fort Bliss is in the Chihuahua Desert of far western Texas and southern New Mexico, north of El Paso (Texas) and south of Alamogordo (New Mexico). The landscape selected for this application consisted of 94 km^2 in the north central portion of Fort Bliss in the McGregor Range of New Mexico.

Climatic Data

A 45-year daily precipitation file for the landscape was adapted from existing precipitation data from the El Paso International Airport weather station. This station is south and at a lower elevation than the landscape for this area, so the daily precipitation data for El Paso was modified by multiplying the daily value by 1.39. This conversion factor was based on a correlation between monthly totals collected by Texas Tech University at a site on Otero Mesa from November 1997 through October 1999 and monthly totals from El Paso International Airport during the same period.

The 45-year average annual precipitation value used for the landscape was 35.05 cm (13.80 in.). Table 1 shows annual precipitation totals and Table 2 shows average monthly values.

Table 1. Annual precipitation totals used in the Fort Bliss application.

Year	Total (cm)	Year	Total (cm)	Year	Total (cm)	Year	Total (cm)
1948	23.06	1960	36.83	1972	36.27	1984	65.41
1949	35.43	1961	31.17	1973	30.45	1985	33.10
1950	27.31	1962	33.58	1974	56.44	1986	49.25
1951	26.26	1963	19.89	1975	25.12	1987	44.30
1952	32.23	1964	21.64	1976	41.05	1988	44.73
1953	17.88	1965	21.87	1977	22.20	1989	29.44
1954	25.81	1966	37.31	1978	50.72	1990	52.02
1955	27.05	1967	23.19	1979	23.60	1991	50.04
1956	22.00	1968	48.64	1980	29.49	1992	46.10
1957	45.31	1969	17.53	1981	51.08		
1958	69.52	1970	24.56	1982	44.40		
1959	20.17	1971	29.39	1983	32.31		

Table 2. Monthly precipitation totals for the Fort Bliss landscape, averaged over a 45-year period.

Month	Average (cm)
Jan	1.79
Feb	1.73
Mar	1.27
Apr	0.84
May	1.40
Jun	2.54
Jul	6.68
Aug	6.12
Sep	5.77
Oct	3.05
Nov	1.40
Dec	2.46

Spatial Data

A 30 m x 30 m cell size was used in this application, resulting in a total of 104,811 cells being included in the landscape mosaic. Topographic data (elevation, aspect, and slope) were entered for each cell, using data supplied electronically by Fort Bliss.

Seven major topographic units were included in the landscape. These were used to define spatial locations of the soil types and initial vegetation types. In TerreSIM, each individual cell retains its specific elevation, aspect, and slope values, and these are used in the model to determine topographic-influenced responses such as surface runoff, soil loss, and amount of precipitation received per unit surface area. By comparison, major topographic units are used to initially define topographic influenced spatial patterns.

The topographic units were: (1) mesa tops, (2) upper northeast-facing slopes, (3) lower northeast-facing slopes, (4) upper southwest-facing slopes, (5) lower southwest-facing slopes, (6) lower flats, and (7) riparian corridors. Locations of each of these topographic units were defined in the model landscape based on topographic maps supplied by Fort Bliss.

Edaphic Data

Multiple soil series occurred within each topographic unit. The locations of each soil series were taken from maps supplied by Fort Bliss. The soil series map and vegetation maps were overlaid, and the soil series most commonly found in each topographic unit was used. This resulted in five soil series used in the application (Table 3). Physical data for each series were provided by the installation. Organic matter and soil nitrogen (total and available) data were taken from soil profiles listed in USDA (1975). Appendix A presents specifics for each soil series.

Table 3. Soil series used in the Fort Bliss landscape application.

Soil Series
Armesa very fine sandy loam
Allamore very cobbly loam
Bissett-Rock outcrop complex
Mariola fine sandy loam
Paisano-Cienega complex

In TerreSIM, the initial values for each of the soil variables are entered for each soil series. These values are available within the TerreSIM Parameters window, and can be modified at runtime, if needed. Appendix A lists the initial values for the simulation runs presented in this report. Values for each of these variables can change during a simulation run, depending on the dynamics of environmental conditions. For example, organic matter content in a given layer will decrease daily because of decomposition, but may also increase daily because of organic matter input from root death or from litter inputs. Nitrogen content will vary on a daily basis because of (1) plant uptake, (2) release from decomposition and mineralization, (3) downward transport through infiltration of soil water, and (4) inputs from atmospheric deposition. Depth of the surface layer may decrease because of erosion. Bulk density, and therefore infiltration rate and water-holding capacity may increase because of soil compaction from vehicle training.

Vegetation Data

Plant Communities

Two sources of data were used to determine which plant communities would be included in the Fort Bliss application: a vegetation map of Fort Bliss and LCTA data from Fort Bliss from 1989 and 1991. The vegetation map indicated that eight vegetation types occurred in the area delineated for the model landscape. These types (listed with the number of cells in the landscape mosaic) included: black grama–blue grama grassland (22,433), black grama–yucca grassland (19,247), black grama –sand muhly grassland (15,382), sideoats grama–sacahuista grassland (10,937), needle-and-thread–black grama grassland (10,790), blue grama–sand dropseed grassland (7,823), creosotebush–black grama shrubland (7,206), and tobosa–blue grama grassland (5,370). In addition, barren or disturbed areas in the landscape were classified as roads (4,441), arroyos (921), and barren lands (261). A multivariate statistical evaluation of the LCTA data (McLendon et al. 1996) suggested a vegetation classification for Fort Bliss that contained 22 vegetation types. The 2 sources of vegetation data were compared (Table 4), and 11 plant communities were defined for the landscape based on this comparison (Table 5).

Table 4. Comparison of vegetation types from the Fort Bliss vegetation map and a multivariate statistical analysis of Fort Bliss LCTA data.

Vegetation Map	Multivariate Classification
Black grama-blue grama	Black grama-blue grama
	Black grama-hairy grama-blue grama
	Black grama/snakeweed-blue grama
Black grama-yucca	Black grama/snakeweed-needlegrass
Black grama-sand muhly	Black grama-sand muhly-bush muhly
Needle-and-thread–black grama	Needlegrass/black grama-sideoats
Blue grama-sand dropseed	Blue grama/snakeweed
	Blue grama-black grama/snakeweed
Tobosa-blue grama	Tobosa-sand muhly/tarbush
	Black grama/tobosa-vine-mesquite
Sideoats grama-sacahuista	Sideoats-sand muhly/buffalograss
	Sideoats-black grama-snakeweed
<u>Shrublands</u>	
Creosotebush-black grama	Creosotebush/sideoats-bush muhly

Table 5. Eleven plant communities used in the model application for the landscape at Fort Bliss, Texas.

Scientific Nomenclature	Common Name
Desert grasslands	
Bouteloua eripoda/Bouteloua gracilis	Black grama/blue grama community
Bouteloua eripoda/Yucca elata	Black grama/yucca community
Bouteloua eripoda/Muhlenbergia arenicola	Black grama/sand muhly community
Bouteloua curtipendula/Nolina texana	Sideoats grama/sacahuista community
Stipa comata /Bouteloua eripoda	Needle-and-thread/black grama community
Bouteloua gracilis/Sporobolus cryptandus	Blue grama/sand dropseed community
Hilaria mutica/Bouteloua gracilis	Tobosa/blue grama community
Desert shrublands	
Larrea tridentata/Bouteloua eripoda	Creosotebush/black grama community
Disturbed and barren lands	
Roads	Road
Arroyos	Arroyo
Barren lands	Barren

The Fort Bliss vegetation map was the primary source for spatial distribution of the 11 plant communities, with some modifications made based on topographic and edaphic considerations. The vegetation map also included over 5,000 cells in nonvegetated conditions, including roads (4,441), arroyos (921), and barren/military (261).

The classification of each cell into one of the 11 plant communities was for initial conditions of each simulation run. Over time, during a simulation run, a cell may change from one community to another, or to a new community, because of successional development or disturbance. For example, a grassland community will shift to a creosotebush community if the abundance of creosotebush increases sufficiently. Conversely, a burned creosotebush community could shift to a grassland community if the fire reduced the creosotebush abundance sufficiently and there was sufficient abundance of grass.

The initial classification used in the original EDYS application is the default initialization used for the TerreSIM application. The TerreSIM user can modify these initial classifications for various model runs within the TerreSIM software by adding new vegetation types, modifying existing vegetation types, or reassigning cells to new or different vegetation communities. These modifications can be accomplished in the TerreSIM Map and TerreSIM Parameters windows (see the TerreSIM Users Manual [2003] for additional details).

Plant Species

The number of plant species included in a TerreSIM simulation is flexible and is specified in the initial parameterization. However many species are selected, the suite remains a simplified representation of the actual vegetation, since some species remain excluded. To account for overall community dynamics (e.g., total aboveground biomass), the ecological contribution of the species not specifically included in the model must be accounted for somehow. This accounting is accomplished in TerreSIM by using composite species. In the model, a composite species consists of a major species plus those minor species most ecologically similar to the respective major species. For example, the composite *Muhlenbergia arenicola* includes *M. arenicola*, *M. arenacea*, and *M. porteri*.

Initial species composition and aboveground biomass values for the plant communities were based on values from validation study plots (McLendon et al. 2000) that had the most-similar composition to the respective plant community in the application (Table 6). Two communities (needlegrass-black grama and sideoats-sacahuista) had no similar validation plot community. Data from the 1989 LCTA data set were used to estimate initial conditions for these two types, using the LCTA needlegrass-black grama-sideoats community for the model's needlegrass-black grama community and the LCTA sideoats-black grama-snakeweed community for the model's sideoats-sacahuista community.

Table 7 shows mean aboveground biomass in the validation plots, sampled in 1998, that were used to calibrate biomass algorithms with the plant communities being modeled. Fourteen species were chosen on the basis of (1) being major species in the validation plots or along the LCTA transects in the area of the landscape, or (2) being important components of the plant communities within specific locations that were included in the landscape. These 14 species became the composite species used in the original EDYS application, and are the defaults used in the TerreSIM application. Values for the remaining 25 species that occurred in the validation plots were included in the values for their respective composite species (Table 8).

Table 6. Comparison of model plant communities to most-similar validation plots compositions.

Plots	Plot Community	Model Community
42, 44, 46	creosotebush-black grama	creosotebush-black grama
28, 38	black grama-blue grama	black grama-blue grama
03	yucca-black grama	black grama-yucca
14, 17, 27	black grama-sand muhly	black grama-sand muhly
	no corresponding type	needlegrass-black grama
30, 35, 41, 45, 48	black grama-creosotebush	blue grama-sand dropseed
25, 34	black grama-tobosa	tobosa-blue grama
	no corresponding type	sideoats-sacahuisata

Table 7. Mean aboveground biomass (g/m^2) in validation plots, sampled in 1998, that most-closely correspond to the model plant communities.

Species	Communities					
	Creosote	**Blckgr1**	**Blckgr2**	**Blckgr3**	**Bluegrm**	**Tobosa**
Ceratoides lanata	0	0	8	t	0	0
Gutierrezia sarothrae	0	0	30	t	t	0
Krameria parvifolia	0	0	0	0	1	0
Koeberlinia spinosa	12	0	0	0	0	0
Larrea tridentata	31	t	0	4	10	9
Opuntia imbricata	0	2	0	0	0	0
Opuntia macrocentra	0	0	0	0	4	0
Opuntia polyacantha	0	0	0	0	2	0
Yucca elata	0	0	249	0	0	0
Aristida purpurea	0	1	0	t	t	1
Bouteloua eriopoda	113	85	80	147	160	156
Bouteloua gracilis	13	15	0	t	8	13
Cenchrus incertus	0	0	0	1	0	0
Enneapogon desvauxii	0	t	0	0	1	t
Erionueron pulchellum	1	1	1	1	t	1
Hilaria mutica	0	0	0	0	0	29
Muhlenbergia arenacea	1	1	0	0	0	3
Muhlenbergia arenicola	6	14	36	34	9	3
Muhlenbergia porteri	14	0	0	0	2	0
Panicum hallii	0	0	0	0	0	t
Scleropogon brevifolius	t	10	0	0	1	3
Setaria leucopila	0	0	1	t	t	0
Sporobolus contractus	6	0	16	0	0	0
Sporobolus cryptandrus	t	1	14	2	9	1
Acourtia nana	2	t	7	0	t	2
Baileya multiradiata	0	0	t	t	0	0
Chaetopappa ericoides	t	t	0	t	t	1
Croton pottsii	0	t	0	3	t	0
Euphorbia lata	t	0	0	t	t	0
Senna bauhinioides	0	0	1	0	0	0
Solanum eleagnifolium	t	0	0	1	1	0
Sphaeralcea coccinea	0	1	0	1	1	1
Talinum aurantiacum	0	0	1	0	0	0
Tetraclea coulteri	0	t	0	0	t	0
Thymophylla acerosa	0	0	0	t	0	0
Zinnia grandiflora	1	t	1	2	1	0
Number						
Plots						

Creoste = creosotebush-black grama
Blckgr1 = black grama-blue grama
Blckgr2 = black grama-yucca
Blckgr3 = black grama-sand muhly
Bluegrm = blue grama-sand dropseed
Tobosa = tobosa-blue grama

Table 8. Fourteen plant species selected as composite species, along with the species included in each composite, in the model application for the Fort Bliss training area landscape.

Composite Species	Common Name	Included Species
Gutierrezia sarothrae	snakeweed	*Ceratoides lanata, Gutierrezia sarothrae*
Larrea tridentate	Creosotebush	*Krameria parvifolia, Koeberlinia spinosa, Larrea tridentata*
Nolina texana	sacahuista	*Nolina texana*
Yucca elata	Yucca	*Opuntia imbricata, Opuntia macrocentra, Opuntia polyacantha, Yucca elata*
Aristida purpurea	purple threeawn	*Aristida purpurea, Cenchrus incertus*
Bouteloua curtipendula	sideoats grama	*Bouteloua curtipendula*
Bouteloua eripoda	black grama	*Bouteloua eriopoda*
Bouteloua gracilis	blue grama	*Bouteloua gracilis, Bouteloua hirsuta, Erioneuron pulchellum*
Hilaria mutica	tobosa	*Hilaria mutica, Scleropogon brevifolius*
Muhlenbergia arenicola	sand muhly	*Enneapogon desvauxii, Muhlenbergia arenacea, Muhlenbergia areniocola, Muhlenbergia porteri*
Sporobolus contractus	mesa dropseed	*Sporobolus contractus*
Sporobolus cryptandrus	sand dropseed	*Panicum hallii, Setari leucopoila, Sporobolus cryptandrus*
Stipa comata	needle-and-thread	*Stipa neomexicana*
Croton pottsii	doveweed	all forbs

Parameterization Data

The TerreSIM software allows the user to modify the initial parameters for the 14 species/composites, as well as allowing additional species/composites to be included. The initial parameterization data for the model species/composites are contained within the TerreSIM Database and can be found in Appendix B. The values for these initial parameters were derived from several sources: (1) site-specific data from the validation plot study funded by USACE (DACA88-98-M-0199, McLendon et al. 2000), (2) data from the scientific literature, (3) data from the SMI database, and (4) personal experience.

Animal Data

Two native animal species were simulated in this application: insects and rabbits. Herbivory by insects and rabbits was assumed to be uniform throughout the landscape and was based on animal densities. Densities used for insects were 3, 6, and 12 individuals per square meter. Rabbits were simulated at densities of 0.30, 0.56, and 0.78 individuals per hectare. These values were based on available literature and estimates from installation personnel and are unchanged from the original EDYS model.

Natural Stressors

Six natural stressors were included in this application: interspecific competition for belowground resources (water, nutrients), drought, nitrogen availability, shading, fire, and herbivory by native animals (insects and rabbits). Ecological responses by each plant species to each of these stressors are modeled using (1) supply and demand and (2) ecophysiological relationships defined by the parameterization matrices (Appendix B). For example, successional patterns are simulated by changes in relative biomass of the species over time in response to the interaction of these stressors. If species A has a higher water use efficiency than species B, species A will produce a higher proportion of biomass than species B in dry years, provided an equal amount of water is available to both species. However, species B may have a different root architecture than species A, which allows species B to access the water in soil layers unavailable to species A. Therefore, species B may be more "protected" from drought than species A because of its deeper root system. In addition, fires may be more frequent in dry years and species B may be better adapted to fire stress than species A. Both of these factors, deeper roots and better adaptation to fire, may provide species B with sufficient competitive advantage over species A to offset the higher water-use efficiency of species A.

Daily precipitation values are used based on the constructed historic data set (Table 1). These constitute the default precipitation level for the application. The values can be modified by the user to increase or decrease these values to simulate above-average precipitation or drought.

The default frequency for natural fire is monthly. Its occurrence and spread are based on appropriate fuel load, moisture content, and a stochastic factor.

Management Scenarios

Management scenarios include optional values for those factors directly influenced by human activities. Seven management options are included in this application: (1) cattle grazing, (2) prescribed fire, (3) movement of livestock tanks, (4) Patriot-missile training, (5) bombing training, (6) vehicle training (M-1 Abrams, M-2 Bradley, High-Mobility Multipurpose Wheeled Vehicle [HMMWV], truck), and (7) bivouacking.

Four stocking rates are included in the application, any one of which can be selected by the user for a particular simulation. The four standard rates are no grazing, light grazing (90 acres per animal unit [ac/AU]), moderate grazing (60 ac/AU), and heavy grazing (45 ac/AU). The user can also designate any alternative stocking rate, rather than only select from the four standard stocking rates. Year-long grazing is assumed for this application.

For the prescribed fire, the user selects which areas are to be burned, when the burn is to take place (month, year), and how often the prescribed fire occurs (e.g., every 4 years). The effectiveness and spatial distribution of the fire are simulated based on the composition, biomass, and distribution of the vegetation in each cell within the burn areas at the time of the fire.

Livestock tanks are available to cattle within the simulation area. The user may elect to make each one available at different times during a simulation run or to move the existing tanks to new locations within the training area. When livestock tanks are included in a simulation run, the model concentrates cattle activity into three zones around each tank, with greatest use (hence greatest rate of herbivory), in the zone closest to each tank, and decreasing use with increasing distance from each tank. The shape of each zone is also influenced by the spatial configuration of fences around each pasture, as designated by Fort Bliss personnel.

Sixteen Patriot-missile training sites are located in the landscape. The user implements training activities by selecting the appropriate missile launch pad, when the training occurs (month, year), and how often (e.g., every other year). Within the missile launch pad area, 70 percent of the aboveground herbaceous vegetation is assumed to convert to litter. Biomass is added to the seedbank for six weedy species (snakeweed, creosotebush, purple threeawn, sand muhly, sand dropseed, and leatherweed croton) to simulate their invasion of the disturbed area post-training activity. The existing vegetation is allowed to recover, with the rate of recovery based on greenout parameters (Table B16, Appendix B), along with competition from the invading weedy species as they germinate and grow.

Bombing training by the German Air Force can be implemented by the user selecting the timing of the training (month, year, frequency), the number of 500-lb and 1000-lb bombs used, the impact footprint, the probability of impact around targets, and whether bombing changes the probability of fire. Each type of ordnance has two potential impact footprints, circular or linear, and the user may specify which both size and type of footprint. TerreSIM simulates impacts in three zones around each target and allows the user to set both the probability of impact within and the width of each zone. This flexibility allows the user to simulate increasing skill by pilots. All aboveground vegetation within a crater is assumed to convert to litter. As for Patriot training, biomass is added to the seedbank for six weedy species to simulate their invasion of the bomb craters.

Vehicle training is implemented by the user selecting (1) which of four vehicle types (M-1 Abrams, M-2 Bradley, HMMWV, truck) and numbers of each type are to be included, (2) which training area the activities are to occur in, (3) the intensity of the training (i.e., how many vehicle miles per vehicle type), and (4) when the training occurs (months, years). Once these parameters are designated, TerreSIM calculates ecological impact in one of two methods, depending on which is designated by the user. In both methods, an impact is associated with each vehicle type on each plant species for each pass of the vehicle (Table B24, Appendix B). In the first method, this calculated impact is distributed stochastically across the designated training area, and in the second method it is averaged over the entire designated training area.

Bivouacking is simulated in a similar manner as vehicle training. The number and frequency of bivouac areas are defined by the user. Each bivouac area is four cell-units in size. The locations can be selected by the user, either directly on the grid display or by inputting Universal Transverse Mercator (UTM) coordinates. All aboveground herbaceous vegetation is assumed to be converted to litter in the bivouac area. The vegetation is allowed to recover starting the month after the bivouac impact, with the rate of recovery based on the greenout parameters for the impacted species (Table B17, Appendix B).

4 Simulation Results

The impact of three factors on the vegetation dynamics at McGregor Range are of primary importance to managers at Fort Bliss: (1) military training, (2) cattle grazing, and (3) prescribed fire. Results of several simulation runs are presented in this report to illustrate the use of TerreSIM to evaluate the relative impacts of each of these three factors, alone and in combination. Average (i.e., historical) precipitation levels were used in all simulation runs.

The vegetation parameter used to evaluate these management scenarios was end-of-growing season (31 October) aboveground biomass (g/m^2). For shrubs, the value was total aboveground biomass (trunks, stems, leaves). For grasses and forbs, it was clippable aboveground biomass (stems, leaves), which is approximately one-half of total aboveground biomass.

Simulated Baseline Conditions

Baseline conditions were defined as the vegetation changes that would occur in the absence of further human impacts from cattle grazing, military training, or prescribed burning. The initial conditions were those typical of present conditions. The simulation run was for 20 years, and moderate levels of native herbivores were allowed to impact the area.

Under these conditions, shrubs increased 35 percent and perennial grasses decreased 23 percent (Table 9). Creosotebush aboveground biomass more than doubled over the 20-year period, and sacahuista increased five-fold. Conversely, snakeweed decreased substantially. Snakeweed is an earlier-seral species than creosotebush in these desert grasslands. Therefore, an increase in creosotebush and a decrease in snakeweed would be the expected successional response. The precipitation regime used in this 20-year scenario was about average for the 45-year period of record for the site (35.88 cm 20-year mean, 35.05 cm 45-year mean; Table 1). Therefore, the increase in creosotebush and sacahuista is not likely to have been caused by a change in precipitation.

Table 9. Model simulation results for vegetation dynamics on McGregor Range at Fort Bliss, Texas, over a 20-year period, under baseline conditions (i.e., no further cattle grazing, military training, or prescribed fire).

Species	End-of Growing Season Biomass (g/m^2)							
	Initial	Year 1	Year 3	Year 5	Year 8	Year 12	Year 15	Year 20
Broom snakeweed	8	22	4	6	3	3	3	1
Creosotebush	15	29	39	40	37	43	44	39
Sacahuista	4	5	7	8	12	16	18	20
Yucca	56	56	54	53	45	58	66	52
Purple threeawn	2	8	3	2	1	1	1	t
Sideoats grama	6	5	6	5	6	3	6	2
Black grama	65	59	51	61	56	65	69	63
Blue grama	21	29	21	45	18	20	48	10
Tobosa	7	12	17	20	13	13	36	10
Sand muhly	16	9	7	9	6	4	8	4
Alkali sacaton	1	4	5	5	6	10	20	11
Sand dropseed	8	14	3	4	2	1	4	2
Needle-and-thread	7	1	1	t	t	2	t	t
Doveweed	8	5	t	t	0	0	0	0
Total shrubs	83	112	104	107	97	120	131	112
Clippable grasses	13	141	114	151	108	119	192	102
Clippable forbs	3 8	5	t	t	0	0	0	0

Most grasses decreased during the 20-year simulation, with blue grama decreasing by 50 percent, sand muhly by 75 percent, and needlegrass by almost 100 percent (Table 9). The site-dominant black grama, however, remained stable and two species, tobosa and mesa dropseed, increased substantially. Decreases in threeawn and sand dropseed should be expected under baseline conditions because both are mid-seral species. Likewise, decreases in blue grama and needlegrass could be expected under 20 years of average precipitation because both species are more characteristic of slightly more mesic conditions than occur on this landscape.

It should also be noted that the simulation results presented in Table 9 are averages for the entire landscape. This landscape is actually a mosaic, consisting of 11 plant communities (Table 5). Vegetation composition varies significantly among these 11 communities (Table 10). In addition, this Fort Bliss application used a minimum cell size of 900 m^2. Therefore, the biomass values for each of the plant species were averaged across this spatial scale. Under actual conditions, many microsites would be distributed within an area of this size. The 900-m^2 area would be a mosaic of vegetation subtypes, including areas under creosotebush with little herbaceous vegetation and areas between the creosotebush canopies with stands of grasses and forbs.

Table 10. Model simulation results of changes in total aboveground biomass (g/m^2) on two of the simulated plant communities on McGregor Range at Fort Bliss, Texas over a 20-year period under baseline conditions.

Species	Black grama-Blue grama			Creosotebush-Black grama		
	Yr 01	Yr 10	Yr 20	Yr 01	Yr 10	Yr 20
Broom snakeweed	5	2	1	1	3	5
Creosotebush	41	47	36	80	103	115
Sacahuista	1	6	5	1	1	1
Yucca	1	2	2	1	t	t
Purple threeawn	12	3	1	4	1	t
Sideoats grama	3	2	1	t	1	1
Black grama	235	472	494	79	116	184
Blue grama	34	117	136	4	9	10
Tobosa	41	85	85	2	5	3
Sand muhly	13	20	15	8	20	20
Alkali sacaton	6	29	45	3	7	21
Sand dropseed	14	4	2	10	4	2
Needle-and-thread	0	0	0	0	0	0
Leatherweed croton	13	t	0	3	0	0
Total trees	48	57	44	83	107	121
Clippable grasses	358	732	779	110	163	241
Clippable forbs	13	t	0	3	0	0

Vegetation dynamics vary significantly among the 11 plant communities forming this landscape. For example, creosotebush more than doubled over the entire landscape over the 20-year simulation (Table 9). However, it decreased by 12 percent in the black grama-blue grama community and increased by 44 percent in the black grama-creosotebush community (Table 10). Similarly, sacahuista increased in the black grama-blue grama grassland, but it did not increase in the creosotebush-black grama shrubland. Overall, blue grama and sand muhly decreased in the landscape, but blue grama increased substantially in the black grama-blue grama grassland and sand muhly increased in the creosotebush-black grama shrubland. These responses emphasize the complex nature of the landscape mosaic. It should always be remembered that averages across the landscape, such as presented in Table 9, are just that, averages, and they tend to obscure very significant localized differences. These localized differences are what are very important ecologically, providing niches for both plant and animal species that would not exist under average conditions. This also illustrates why simulation modeling on a landscape scale must provide for simulation of differences on the localized scale.

Simulated Cattle Grazing

Cattle grazing had an effect on vegetation dynamics over a 10-year simulation period, but the difference between light (90 Ac/AU) and moderate (60 Ac/AU) stocking rates was small (Table 11). Light grazing by cattle resulted in an 11 percent increase in creosotebush and a 7 percent decrease in perennial grasses, compared with no grazing. Moderate grazing resulted in a 13 percent increase in creosotebush and an 8 percent decrease in perennial grasses.

Cattle grazing had little effect on the dynamics of the woody species. Over a 10-year period, light grazing increased creosotebush by 11 percent compared with no grazing, and moderate grazing increased creosotebush by 13 percent (Table 11). Compared with no cattle grazing, Sacahuista decreased slightly with moderate grazing, yucca decreased 12 percent under light grazing and 22 percent with moderate grazing, while snakeweed remained unchanged. Overall woody species totals showed a 3 percent decrease with light grazing and 8 percent decrease with moderate grazing, compared with no cattle grazing.

Cattle grazing also had an effect on species composition of the grass component (Table 11). Grazing did not affect production of threeawn, mesa dropseed, or needlegrass, and had only a minor effect on tobosa and sand dropseed. Sideoats grama was not affected by light grazing, but increased slightly under moderate grazing. Blue grama and sand muhly decreased slightly under light grazing and slightly more under moderate grazing. The major impact of cattle grazing was on black grama, which decreased 15 percent under light grazing and 17 percent under moderate grazing, over 10 years.

These responses reflect both the preferences of the individual grass species and their relative abundances. Black grama is a preferred forage species by cattle, it is the most abundant species in the landscape, and it is highly palatable in all seasons. It is not surprising, therefore, that this species received most of the grazing pressure. Again, simulation modeling on the landscape scale should allow for these differences among species. All grasses are not the same, and pooling them would result in the loss of very important ecological responses in the simulation results.

Table 11. Model simulation results of vegetation dynamics (g/m^2) on McGregor Range at Fort Bliss, Texas over a 10-year period, under three levels of cattle grazing.

Species	Year 01			Year 03			Year 05			Year 10		
	No	Lt	Md	No	Lt	Md	No	Lt	Md	No	Lt	Md
Broom snakeweed	23	23	23	4	4	4	6	6	6	4	4	4
Creosotebush	29	29	29	39	39	40	40	42	43	38	42	43
Sacahuista	5	5	5	7	7	6	8	7	6	14	13	11
Yucca	56	57	57	54	54	53	53	51	48	49	43	38
Purple threeawn	8	7	7	3	2	2	2	2	2	1	1	1
Sideoats grama	5	4	4	6	6	6	5	5	5	10	10	12
Black grama	59	56	56	51	45	45	61	53	51	86	73	71
Blue grama	29	28	28	21	21	20	45	44	43	46	45	44
Tobosa	12	13	13	17	17	17	20	21	21	25	24	24
Sand muhly	9	8	8	7	5	4	9	7	7	10	9	8
Alkali sacaton	4	4	4	5	5	5	5	5	5	13	13	13
Sand dropseed	14	13	13	3	5	5	4	6	8	10	11	11
Needle-and-thread	1	1	1	1	1	1	t	t	t	1	1	1
Doveweed	5	5	5	t	t	t	t	t	t	0	0	0
Total shrubs	113	114	114	104	104	103	107	106	103	105	102	96
Clippable grasses	141	134	134	114	107	105	151	143	142	202	187	185
Clippable forbs	5	5	5	t	t	t	t	t	t	0	0	0

No = no livestock grazing
Lt = light livestock grazing (90 Ac/AU)
Md = moderate livestock grazing (60 Ac/AU)

Simulated Prescribed Fire

The simulated prescribed fire management scenario was that management units 4 and 5, about 40 percent of the total landscape area, were burned in February of Year 12. The prescribed fire scenario for each burn was that every cell within the respective management areas was exposed to the fire (i.e., every cell edge was "torched"). Whether or not the specific cell burned depended on its fuel load.

This fire scenario resulted in several ecological responses (Table 12). The most obvious was a 25 percent decrease in shrubs, compared with the unburned scenario. The landscape supported an average of 84 g/m^2 of shrubs when burned. This compares to an initial shrub biomass of 83 g/m^2 (Table 9). Therefore, fire eliminated the increase of shrubs associated with 20 years of baseline conditions. Of the four shrub species, creosotebush and yucca had the greatest reductions.

Fire also had an impact on the perennial grasses, reducing their aboveground production slightly (4 percent, Table 12). The effect of fire was most pronounced on black grama (30 percent decrease), blue grama (20 percent decrease), tobosa (100 percent increase), and mesa dropseed (73 percent increase). Black grama is known to be fire-sensitive in this ecosystem (McLendon et al. 2000) and tobosa is a fire-tolerant species.

Table 12. Model simulation results of effects of prescribed fire in year 12 on the vegetation (g/m^2) of McGregor Range at Fort Bliss, Texas, without livestock grazing.

Species	Unburned			Burned		
	Year 10	Year 12	Year 20	Year 10	Year 12	Year 20
Broom snakeweed	4	3	1	4	2	1
Creosotebush	38	43	39	38	21	28
Sacahuista	14	16	20	14	12	17
Yucca	49	58	52	49	28	38
Purple threeawn	1	1	t	1	1	t
Sideoats grama	10	3	2	10	3	2
Black grama	86	65	63	86	42	44
Blue grama	46	20	10	46	15	8
Tobosa	25	13	10	25	10	20
Sand muhly	10	4	4	10	4	3
Alkali sacaton	13	10	11	13	9	19
Sand dropseed	10	1	2	10	1	2
Needle-and-thread	1	2	t	1	1	t
Doveweed	0	0	0	0	0	0
Total shrubs	105	120	112	105	63	84
Clippable grasses	202	119	102	202	86	98
Clippable forbs	0	0	0	0	0	0

When prescribed fire is combined with moderate grazing by cattle, several primary changes occur over prescribed fire with no grazing (Table 13). First, the effectiveness of fire in reducing creosotebush is reduced. Without grazing but with fire, creosotebush increased 87 percent over initial conditions over a 20-year period (Tables 9 and 13). With moderate grazing and with fire, creosotebush biomass increased 147 percent. With moderate grazing and without fire, however, creosotebush increased 240 percent (Table 13). Therefore, grazing reduced the effectiveness of fire by about 50 percent (from an 87 to a 147 percent increase), but given that moderate cattle grazing will occur, fire reduces the rate of increase in creosotebush by about 40 percent (from 240 percent without fire, to 147 percent with fire).

The combination of fire and moderate cattle grazing reduced perennial grass biomass at the end of 20 years by 18 percent compared with fire alone and by 5 percent compared with grazing alone (Table 13). Black grama was most impacted because it is the preferred forage species and is fire-sensitive.

Table 13. Model simulation results of the effect of moderate cattle grazing (60 Ac/AU) and prescribed fire in Year 12 on aboveground plant biomass (g/m^2) on McGregor Range at Fort Bliss, Texas.

Species	No Grazing				Moderate Grazing			
	Unburned		Burned		Unburned		Burned	
	10 yr	20 yr	10 yr	20 yr	10 yr	20 yr	10 yr	20 yr
Broom snakeweed	4	1	4	1	4	1	4	1
Creosotebush	38	39	38	28	43	51	43	37
Sacahuista	14	20	14	17	11	18	11	15
Yucca	49	52	49	38	38	40	38	35
Purple threeawn	1	t	1	t	1	t	1	t
Sideoats grama	10	2	10	2	11	2	11	2
Black grama	86	63	86	44	71	48	71	29
Blue grama	46	10	46	8	44	9	44	7
Tobosa	25	10	25	20	24	7	24	18
Sand muhly	10	4	10	3	8	4	8	4
Alkali sacaton	13	11	13	19	13	11	13	16
Sand dropseed	10	2	10	2	11	3	11	4
Needle-and-thread	1	t	1	t	1	t	1	t
Doveweed	0	0	0	0	0	0	0	0
Total shrubs	105	112	105	84	96	110	96	88
Clippable grasses	202	102	202	98	184	84	184	80
Clippable forbs	0	0	0	0	0	0	0	0

Effect of Military Training

Military training was simulated as: (1) wheeled vehicles only, (2) wheeled and tracked vehicles together, (3) Patriot-missile training, and (4) bombing training. Wheeled vehicle training (as provided by Fort Bliss) consisted of 500 vehicle-miles by trucks and 1000 vehicle-miles by HMMWVs per year. Tracked vehicles were simulated as 500 vehicle-miles by Bradley Fighting Vehicles and 1000 vehicle-miles by Abrams Main Battle Tanks per year. The training was averaged across training area 4 in June of the first year, then every third year thereafter; training area 19 in June of the second year, then every third year thereafter; and training area 16 in June of the third year, then every third year thereafter. For Patriot missiles, training was simulated in half the missile sites in the first year, then every-other year thereafter; and the other sites in the second year, then every other year thereafter. In each simulated year, two sites were used in February, two in April, two in June, and two in September. Bombing training was simulated as occurring in April, June, and August of each year. Ordnance totals were 10,000 each for 500- and 1000-lb bombs.

Training with wheeled vehicles, at the intensity and frequency simulated, reduced shrub biomass by 8 percent, compared with baseline conditions (Table 14). All shrubs except snakeweed had lower biomass values with wheeled-vehicle training than under baseline conditions. This impact was the result of vehicles crushing the shrubs. The impact of wheeled and tracked vehicles resulted in a greater reduction in shrubs than wheeled vehicles only.

Wheeled-vehicle training had only a slight effect (2 percent decrease) on grass production (Table 14). Black grama production declined by 6 percent, compared with baseline conditions, tobosa increased by 10 percent, and mesa dropseed increased by 9 percent. The combination of wheeled- and tracked-vehicle training decreased grass production by 10 percent, compared with baseline, again with most of this impact on black grama.

When combined with moderate grazing, vehicle training had a somewhat different impact on the vegetation compared with moderate grazing without vehicle training. Moderate grazing, without fire and without training, increased creosotebush biomass from 39 g/m^2 under baseline conditions (Table 9), to 51 g/m^2, after 20 years (Table 13). Creosotebush biomass under the wheeled-vehicle training and grazing scenario increased to 45 g/m^2, and to 42 g/m^2 under the combined-vehicle training and grazing scenario (Table 14). Therefore, creosotebush increased more under both types of training when combined with grazing than without grazing, but the training reduced the amount of creosotebush compared with grazing alone.

Table 14. Model simulation results of the effect of military training on vegetation (g/m^2) on McGregor Range at Fort Bliss, Texas, with and without livestock grazing.

Species	Wheeled Vehicles				Wheeled and Tracked Vehicles			
	No Grazing		Moderate Grazing		No Grazing		Moderate Grazing	
	Year 03	Year 20	Year 03	Year 20	Year 03	Year 20	Year 03	Year 20
Broom snakeweed	5	1	4	2	5	1	4	2
Creosotebush	38	35	38	45	36	33	37	42
Sacahuista	6	18	6	16	6	15	6	13
Yucca	53	49	52	39	52	45	51	36
Purple threeawn	3	t	3	t	4	1	3	1
Sideoats grama	5	2	5	2	6	2	5	2
Black grama	51	59	44	46	49	56	43	42
Blue grama	21	10	20	9	21	10	20	9
Tobosa	16	11	16	8	16	12	16	9
Sand muhly	7	4	4	5	7	5	5	5
Alkali sacaton	5	12	5	11	5	12	4	11
Sand dropseed	4	2	5	3	5	2	6	3
Needle-and-thread	1	t	1	t	1	t	1	t
Doveweed	t	t	t	t	t	t	t	t
Total shrubs	102	103	100	102	99	94	98	93
Clippable grasses	113	100	103	84	114	100	103	82
Clippable forbs	t	t	t	t	t	t	t	t

Wheeled-vehicle training combined with grazing did not have an increased impact on grass production overall, compared with grazing alone, but did have a somewhat different impact on species composition (Tables 13 and 14). Wheeled-vehicle training with grazing resulted in a decrease in black grama and an increase in tobosa and sand muhly, compared with moderate grazing without training. Combined-vehicle training with grazing reduced overall grass biomass by 2 percent, compared with wheeled-vehicle training with grazing (Table 14). The combined-vehicle training and grazing scenario further decreased black grama, but increased threeawn and tobosa.

Patriot-missile training combined with moderate cattle grazing, had an intermediate effect on vegetation compared with moderate cattle grazing and cattle grazing plus vehicle training. The Patriot-grazing combination resulted in more creosotebush than either vehicle-grazing combination (Tables 14 and 15), but less than grazing alone (Table 13). Patriot-missile training, in combination with grazing, resulted in less black grama, blue grama, and mesa dropseed, and more tobosa than moderate grazing alone. The impact of Patriot-missile training on black grama was greater than with wheeled-vehicle training but less than with combined-vehicle training (Tables 14 and 15).

Bombing training, combined with moderate cattle grazing, decreased overall shrub biomass on the landscape, compared with cattle grazing alone (Tables 14 and 15), but this decrease was less than with any other type of training (e.g., when combined with cattle grazing, bombing resulted in the greatest increase in shrubs of all four types of training). However, bombing also had less of a detrimental impact on black grama than any of the other training activities.

Table 15. Model simulation results of effects of Patriot-missile and bombing training on the vegetation (g/m^2) of the McGregor Range at Fort Bliss, Texas, with moderate livestock grazing.

Species	Patriot Missile Training			Bombing Training		
	Year 01	Year 10	Year 20	Year 01	Year 10	Year 20
Broom snakeweed	22	4	2	22	4	1
Creosotebush	29	42	49	29	43	51
Sacahuista	5	11	18	5	11	18
Yucca	56	37	39	56	37	40
Purple threeawn	7	1	t	7	1	t
Sideoats grama	4	11	2	4	11	2
Black grama	55	65	44	57	70	47
Blue grama	27	43	8	28	44	9
Tobosa	13	26	9	13	24	8
Sand muhly	7	8	4	8	8	4
Alkali sacaton	4	12	10	4	12	11
Sand dropseed	13	11	3	13	11	3
Needle-and-thread	1	1	t	1	1	t
Doveweed	5	t	t	5	t	t
Total shrubs	112	94	108	112	95	110
Clippable grasses	131	178	80	135	182	84
Clippable forbs	5	t	t	5	t	t

In summary, military training had a measurable impact on vegetation dynamics, but this impact was less than the impact from cattle grazing. In addition, the impact varied by type of training and the impact increased when combined with cattle grazing. In general, when combined with grazing, training decreased the amount of shrubs and some grasses, especially black grama, compared with cattle grazing only.

Water Yield

Changes in water yield were simulated based on daily balances among water inputs (precipitation), water use by plants, water storage in the soil profiles, and water export past the rooting zones of the plants.

Under baseline conditions (no prescribed fire, no cattle grazing, no military training), subsurface export was about 67,000 acre-feet for the entire landscape (23,309 acres) over the 20 years of the simulation (Table 16), or about 15 percent of precipitation. Another 1100 acre-feet would be expected to be produced as surface export (runoff). The various management scenarios had little effect on total export (runoff plus subsurface export) from the landscape (Table 16). All management scenarios increased subsurface export slightly over baseline conditions, but the increase was never much more than 5 percent, with the maximum subsurface export occurring under the training and grazing combination. Maximum surface runoff (1463 acre-feet) occurred under the grazing plus fire scenario (Table 17). This was 28 percent greater than runoff under baseline conditions.

Table 16. Water balance (20-year totals, in acre-feet) based on model simulations for the McGregor Range at Fort Bliss, Texas.

	Management Scenario				
	Baseline	Baseline + Fire	Grazing	Grazing + Fire	Training + Grazing
Precipitation	456,942	456,942	456,942	456,942	456,942
Evaporation	39,536	38,986	37,717	39,067	37,993
Transpiration	360,135	360,208	360,214	358,868	358,945
Runoff	1,142	1,256	1,328	1,463	1,351
Subsurface export	66,811	67,101	68,284	68,092	69,223
Total Export/ Precipitation	0.149	0.150	0.152	0.152	0.154

Grazing is at a moderate stocking rate of cattle.
Fire regime is to burn every 12 years.
Total export is subsurface export plus runoff.
Evaporation, transpiration, runoff, and subsurface export values do not total to precipitation value because of differences in soil moisture storage between initial conditions and the end of Year 20.

Table 17. Comparison of simulated aboveground biomass values (g/m^2) after 20 years of baseline, grazing, vehicle training, and grazing plus vehicle training scenarios, all with prescribed fire.

Species	Baseline	Grazing	Training	Grazing + Training
Broom snakeweed	1	1	1	2
Creosotebush	28	37	25	32
Sacahuista	17	15	13	11
Yucca	38	35	34	31
Purple threeawn	t	t	1	1
Sideoats grama	2	2	2	2
Black grama	44	29	40	27
Blue grama	8	7	8	7
Tobosa	20	18	22	20
Sand muhly	3	4	4	4
Alkali sacaton	19	16	18	14
Sand dropseed	2	4	3	4
Needle-and-thread	t	t	t	t
Doveweed	0	0	t	t

Tree biomass values are total aboveground.
Herbaceous values are clippable biomass.
Grazing is at a moderate stocking rate (60 Ac/AU) of cattle.

5 Conclusions

Model simulations indicate that the two most important factors affecting vegetation dynamics on the Fort Bliss training area landscape are (1) fire regime and (2) cattle grazing. In the absence of fire, either natural or prescribed, an increase in shrubs, primarily creosotebush, and a corresponding, though lesser, decrease in perennial grasses will occur. These are natural successional changes. Without fire, this grassland-shrubland complex will gradually shift to more of a desert shrubland. In the absence of livestock grazing, one fire in 20 years was sufficient to keep the shrub component in the landscape stable. More frequent fires might reduce the amount of shrubs but would probably decrease the productivity of black grama substantially. Less frequent fires might result in slightly more shrubs but would likely favorably affect black grama. An earlier report (McLendon et al. 2000) recommended that fire frequency should not be more frequent than once every 15 years. Results from the simulations reported in this report suggest that the fires should be even less frequent, perhaps once every 20–25 years.

Moderate cattle grazing (60 Ac/AU) resulted in a 31 percent increase in creosotebush, compared with no grazing, over a 20-year period in the absence of fire. Grazing reduced perennial grass biomass by 18 percent, with black grama accounting for the largest percentage of the decrease. Although moderate cattle grazing without fire resulted in an increase in shrubs and a decrease in grasses, the fundamental characteristics of the vegetation remained the same. Therefore, the simulations indicate that the landscape can support moderate cattle grazing for at least 20 years, provided that precipitation is average or above average.

With fire, moderate grazing resulted in less shrub biomass than occurred under baseline conditions (no fire, no grazing). Therefore, fire eliminated the impact of grazing relative to an increase in shrubs. However, the combination of fire and grazing resulted in even lower production of grasses than with grazing alone. Black grama was particularly sensitive to this combination of stressors.

Based on these results, livestock grazing should be excluded from burned areas for at least 1 year with average or above average precipitation to allow for grass recovery. Excluding grazing following fire will result in more productive grass communities, with an increase in productivity proportional to an increase in length of exclusion time. This result is especially true for black grama.

Military training had an impact on vegetation dynamics on this landscape, but this impact, and the levels used in the simulations, was less than that from livestock grazing. All types of training evaluated in these simulations affected the vegetation, but the degree of their impact had a distinct order. Combined training with wheeled and tracked vehicles had the most substantial impact, followed by wheeled-vehicle training, Patriot-missile training, and bombing.

In summary, the results of these simulations indicate that the landscape can support moderate levels of military training combined with cattle grazing for at least 20 years, provided precipitation remains at least at average levels. Under this combined land-use scenario, shrubs will increase across the landscape, and grasses, especially black grama, will decrease. Periodic rest from both training and grazing, especially if combined with the proper use of prescribed fire, would likely result in a lower increase in shrubs and a lower decrease in grasses. As the frequency and duration of rest increases, the greater the benefit to grasses and the slower the increase in shrubs.

Based on the results of these simulations, the elimination of cattle grazing from this landscape would slow the rate of decrease of black grama, even as military training continued. Without cattle grazing, fire could be used more effectively in reducing the amount of shrubs present, while minimizing the negative impact of fire on black grama.

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Appendix A: Soil Series

Table A1. Armesa very fine sandy loam.

Layer	Layer Name	Depth (mm)	Wilting Point	Field Capacity	Saturation	Organic Matter (g/m^2)	Total N (g/m^2)
1	A	25	0.042	0.152	0.480	190.8	0.00095
2	A	51	0.042	0.152	0.480	389.2	0.00195
3	Bw	127	0.042	0.152	0.480	775.4	0.00310
4	Bk1	152	0.070	0.215	0.480	870.0	0.00326
5	Bk2	216	0.070	0.215	0.480	1236.3	0.00464
6	Bk2	216	0.070	0.215	0.480	1071.5	0.00348
7	Bk3	127	0.070	0.215	0.480	581.5	0.00174
8	Bk4	186	0.070	0.215	0.480	709.7	0.00177
9	Bk4	186	0.070	0.215	0.480	709.7	0.00177
10	Bk4	186	0.070	0.215	0.480	567.8	0.00114
11	Bk4	186	0.070	0.215	0.480	425.8	0.00064
12	Bk4	187	0.070	0.215	0.480	24.1	0.00016
13	Bk4	187	0.070	0.215	0.480	214.1	0.00016
Total		2032				7955.9	0.02477

Table A2. Allamore very cobbly loam.

Layer	Layer Name	Depth (mm)	Wilting Point	Field Capacity	Saturation	Organic Matter (g/m^2)	Total N (g/m^2)
1	A	25	0.096	0.181	0.480	190.8	0.00095
2	A	25	0.096	0.181	0.480	190.8	0.00095
3	A	26	0.096	0.181	0.480	158.7	0.00063
4	Bk	44	0.087	0.147	0.480	128.2	0.00051
5	Bk	21	0.087	0.147	0.480	96.2	0.00029
6	Bk	21	0.087	0.147	0.480	96.2	0.00029
7	Bk	21	0.087	0.147	0.480	61.1	0.00012
8	Bk	20	0.087	0.147	0.480	45.8	0.00007
9	Bk	20	0.087	0.147	0.480	45.8	0.00007
10	Bk	20	0.087	0.147	0.480	30.5	0.00003
11	Bk	20	0.087	0.147	0.480	15.3	0.00001
12	Bk	20	0.087	0.147	0.480	7.6	0.00000
13	Bk	20	0.087	0.147	0.480	7.6	0.00000
Total		279				1074.5	0.00393

Table A3. Bissett-Rock outcrop complex.

Layer	Layer Name	Depth (mm)	Wilting Point	Field Capacity	Saturation	Organic Matter (g/m^2)	Total N (g/m^2)
1	A	25	0.071	0.181	0.480	190.8	0.00095
2	A	26	0.071	0.181	0.480	198.4	0.00099
3	Bk	17	0.166	0.226	0.480	103.8	0.00042
4	Bk	17	0.166	0.226	0.480	103.8	0.00042
5	Bk	16	0.166	0.226	0.480	73.3	0.00022
6	Bk	16	0.166	0.226	0.480	73.3	0.00022
7	Bk	16	0.166	0.226	0.480	48.8	0.00010
8	Bk	16	0.166	0.226	0.480	36.6	0.00005
9	Bk	16	0.166	0.226	0.480	36.6	0.00005
10	Bk	16	0.166	0.226	0.480	24.4	0.00002
11	Bk	16	0.166	0.226	0.480	12.2	0.00001
12	Bk	16	0.166	0.226	0.480	6.1	0.00000
13	Bk	16	0.166	0.226	0.480	6.1	0.00000
Total		229				914.3	0.00346

Table A4. Mariola fine sandy loam.

Layer	Layer Name	Depth (mm)	Wilting Point	Field Capacity	Saturation	Organic Matter (g/m^2)	Total N (g/m^2)
1	A	25	0.080	0.125	0.480	190.8	0.00095
2	A	77	0.080	0.125	0.480	5929.7	0.02965
3	Bt	203	0.132	0.185	0.480	1239.4	0.00496
4	Btk	203	0.132	0.185	0.480	1161.9	0.00436
5	Bk	203	0.132	0.185	0.480	1161.9	0.00436
6	Bkm1	178	0.132	0.185	0.480	883.0	0.00287
7	Bkm2	178	0.132	0.185	0.480	815.1	0.00245
8	Bkm2	178	0.132	0.185	0.480	679.2	0.00170
9	Bkm2	178	0.132	0.185	0.480	679.2	0.00170
10	2Bk	152	0.145	0.195	0.480	464.0	0.00093
11	2Bk	152	0.145	0.195	0.480	348.0	0.00052
12	2Bk	152	0.145	0.195	0.480	174.0	0.00013
13	2Bk	152	0.145	0.195	0.480	175.1	0.00013
Total		2732				13901.3	0.05470

Table A5. Paisano-Cienega complex.

Layer	Layer Name	Depth (mm)	Wilting Point	Field Capacity	Saturation	Organic Matter (g/m^2)	Total N (g/m^2)
1	A	25	0.058	0.068	0.480	190.8	0.00095
2	A	51	0.058	0.068	0.480	389.2	0.00195
3	Bk	127	0.058	0.068	0.480	775.4	0.00310
4	Bkm	169	0.068	0.078	0.480	1031.8	0.00413
5	Bkm	169	0.068	0.078	0.480	773.8	0.00232
6	Bkm	169	0.068	0.078	0.480	773.8	0.00232
7	BCk	188	0.068	0.078	0.480	573.9	0.00115
8	BCk	189	0.068	0.078	0.480	432.7	0.00065
9	BCk	189	0.068	0.078	0.480	432.7	0.00065
10	BCk	189	0.068	0.078	0.480	288.5	0.00029
11	BCk	189	0.068	0.078	0.480	144.2	0.00007
12	BCk	189	0.068	0.078	0.480	72.1	0.00002
13	BCk	189	0.068	0.078	0.480	72.1	0.00002
Total		2032				5951.1	0.01761

Appendix B: Initial Parameter Matrices for the Fort Bliss Application

A TerreSIM application requires both an initial spatial representation of the plant communities across the simulated landscape and initial biomass values for each of the plant species in each of the plant communities. Table B1 lists the initial above-ground biomass values used for the Fort Bliss TerreSIM application. Values for the various species were developed using these biomass:cover ratios and the cover values from the Fort Bliss LCTA data.

The biomass values from Table B1 specify how much aboveground biomass is to be entered for each species. However, the model also requires a plant-part allocation (distribution) of this biomass (i.e., how much of the initial biomass is leaves, how much is stems, etc.). Table B2 provides this initial allocation of the biomass into plant parts.

Table B1. Initial biomass.

Species	Black grama Blue grama	Black grama Yucca	Black grama Sand Muhly	Sideoats grama Sacahuista	Needle-thread Black grama
Broom snakeweed	0.70	89.80	1.63	7.22	0.00
Creosotebush	14.44	0.00	4.48	15.59	4.62
Sacahuista	0.00	0.00	0.00	32.21	0.00
Yucca	0.23	288.73	0.00	1.74	0.00
Purple threeawn	1.63	0.88	0.75	5.75	8.25
Sideoats grama	0.12	1.04	0.12	39.11	18.69
Black grama	144.97	71.96	153.06	6.14	46.36
Blue grama	18.80	0.00	1.36	27.23	28.59
Tobosa	8.60	0.00	0.69	0.00	0.00
Sand muhly	8.70	44.51	16.68	24.53	9.81
Alkali sacaton	0.00	0.00	0.00	0.00	0.00
Sand dropseed	1.86	34.76	5.13	3.62	3.72
Needle-and-thread	0.00	0.00	0.00	0.00	80.17
Leatherweed croton	2.00	14.92	7.33	32.90	6.40

Table B1 (Cont'd). Initial biomass.

	Blue grama Alkali sacaton	Creosote-bush black grama	Tobosa Blue grama	Roads	Arroyos	Barren
Broom snakeweed	0.00	0.23	0.00	0.00	0.00	0.00
Creosotebush	44.61	61.07	24.69	0.00	0.00	0.00
Sacahuista	0.00	0.00	0.00	0.00	0.00	0.00
Yucca	0.00	0.12	0.00	0.00	0.00	0.00
Purple threeawn	1.13	1.13	1.25	0.00	0.00	0.00
Sideoats grama	0.46	0.69	7.04	0.00	0.00	0.00
Black grama	0.00	122.37	0.00	0.00	0.00	0.00
Blue grama	218.95	7.63	6.54	0.00	0.00	0.00
Tobosa	0.00	1.61	104.69	0.00	0.00	0.00
Sand muhly	10.67	13.61	8.69	0.00	0.00	0.00
Alkali sacaton	16.21	0.70	0.00	0.00	0.00	0.00
Sand dropseed	0.00	5.48	1.75	0.00	0.00	0.00
Needle-and-thread	0.00	0.00	0.00	0.00	0.00	0.00
Leatherweed croton	9.73	5.33	1.07	0.00	0.00	0.00

Table B2. Allocation (mature).

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Broom snakeweed	0.41	0.08	0.29	0.14	0.08	0.00
Creosotebush	0.34	0.06	0.20	0.30	0.10	0.00
Sacahuista	0.57	0.14	0.04	0.09	0.16	0.00
Yucca	0.57	0.13	0.04	0.10	0.16	0.00
Purple threeawn	0.36	0.53	0.02	0.02	0.07	0.00
Sideoats grama	0.07	0.18	0.10	0.25	0.40	0.00
Black grama	0.13	0.50	0.10	0.10	0.17	0.00
Blue grama	0.29	0.52	0.05	0.02	0.12	0.00
Tobosa	0.04	0.11	0.11	0.05	0.69	0.00
Sand muhly	0.22	0.33	0.08	0.10	0.27	0.00
Alkali sacaton	0.31	0.46	0.03	0.08	0.12	0.00
Sand dropseed	0.31	0.46	0.03	0.08	0.12	0.00
Needle-and-thread	0.10	0.20	0.15	0.15	0.40	0.00
Leatherweed croton	0.20	0.05	0.19	0.09	0.47	0.00

The first step in determining the allocation values for each species is to determine the root:shoot ratios. These ratios are taken from the literature for each species or, if data are lacking for the species, the most-similar species. Literature root:shoot values are of two types: (1) ratios for mature plants and (2) ratios for plants less than 1 year old. The two ratios may be very different for the same species, especially for herbaceous perennials. For example, mature blue grama plants have root:shoot ratios on the order of 2.8, compared with a ratio for annual production of 0.25. The reason for the difference is that most of the aboveground biomass in herbaceous perennials is annual (i.e., it dies at the end of each growing season). In contrast, much of the belowground biomass is perennial. Over time, therefore, the proportional amount of roots increases. Cumulative ratios are used in Table B2. Ratios for annual production are used in Table B3.

The root:shoot ratio is used to determine how much root biomass should be added to the initial shoot biomass provided by Table B1, to determine total initial biomass for each species. Total initial root biomass is then allocated between coarse and fine roots.

Initial aboveground biomass is allocated into trunk (crown for grasses), stems, leaves, and seeds (flowers + seeds). Values for all species were estimated.

The biomass values resulting from the application of Table B2 are only initial values used to begin a simulation. As the simulation progresses, these biomass values change on a daily basis, in response to the dynamics of growth, senescence, herbivory, fire, training, etc.

Table B3 provides the allocation values for monthly production. For each gram of dry matter biomass produced by a plant species, a certain portion goes to coarse roots, a portion to fine roots, a portion to trunk, etc.

Table B4 provides the allocation values for production in a month when either dormancy is broken (e.g., spring green-up) or regrowth is triggered following a major defoliation event (e.g., heavy grazing, trampling, fire). The primary difference between this matrix and the current-growth allocation matrix (Table B2) is that in green-out there is no allocation to coarse roots and to grass trunks. These are the primary storage regions for nonstructural carbohydrates, which are used initially to produce regrowth (Stoddart et al. 1975; Garza et al. 1994).

Table B3. Allocation (Current).

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Broom snakeweed	0.08	0.22	0.20	0.25	0.25	0.00
Creosotebush	0.09	0.26	0.20	0.20	0.25	0.00
Sacahuista	0.10	0.25	0.25	0.01	0.39	0.00
Yucca	0.10	0.30	0.20	0.01	0.39	0.00
Purple threeawn	0.09	0.26	0.13	0.12	0.40	0.00
Sideoats grama	0.10	0.25	0.16	0.15	0.34	0.00
Black grama	0.09	0.27	0.15	0.12	0.37	0.00
Blue grama	0.09	0.27	0.17	0.05	0.42	0.00
Tobosa	0.11	0.26	0.16	0.15	0.32	0.00
Sand muhly	0.09	0.26	0.14	0.15	0.36	0.00
Alkali sacaton	0.10	0.25	0.17	0.13	0.35	0.00
Sand dropseed	0.07	0.23	0.10	0.25	0.35	0.00
Needle-and-thread	0.09	0.27	0.14	0.13	0.37	0.00
Leatherweed croton	0.05	0.15	0.20	0.10	0.50	0.00

Table B4. Green-out allocation.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Broom snakeweed	0.00	0.10	0.00	0.30	0.60	0.00
Creosotebush	0.00	0.20	0.00	0.10	0.70	0.00
Sacahuista	0.00	0.30	0.00	0.01	0.69	0.00
Yucca	0.00	0.35	0.00	0.01	0.64	0.00
Purple threeawn	0.00	0.10	0.00	0.20	0.70	0.00
Sideoats grama	0.00	0.10	0.00	0.30	0.60	0.00
Black grama	0.00	0.10	0.00	0.30	0.60	0.00
Blue grama	0.00	0.10	0.00	0.05	0.85	0.00
Tobosa	0.00	0.10	0.00	0.20	0.70	0.00
Sand muhly	0.00	0.10	0.00	0.25	0.65	0.00
Alkali sacaton	0.00	0.10	0.00	0.20	0.70	0.00
Sand dropseed	0.00	0.10	0.00	0.30	0.60	0.00
Needle-and-thread	0.00	0.10	0.00	0.20	0.70	0.00
Leatherweed croton	0.00	0.05	0.00	0.35	0.60	0.00

Table B5 provides the allocation values for production in months in which flowering and seed production occurs. For woody plants, 50 percent of trunk and stem growth and 10 percent of leaf growth are diverted to seeds. For herbaceous perennials, 100 percent of coarse root and trunk growth and 50 percent of leaf growth are diverted to seeds. For annuals, all growth is diverted to seeds. Some exceptions are made for species that are typically heavy seed producers or for species that are poor seed producers.

Table B5. Seed month allocation.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Broom snakeweed	0.00	0.10	0.00	0.00	0.15	0.75
Creosotebush	0.00	0.10	0.00	0.00	0.15	0.75
Sacahuista	0.00	0.10	0.00	0.00	0.10	0.80
Yucca	0.00	0.05	0.00	0.00	0.10	0.85
Purple threeawn	0.00	0.05	0.00	0.00	0.20	0.75
Sideoats grama	0.00	0.10	0.00	0.00	0.20	0.70
Black grama	0.00	0.10	0.00	0.20	0.30	0.40
Blue grama	0.00	0.05	0.00	0.00	0.10	0.85
Tobosa	0.00	0.10	0.20	0.00	0.30	0.40
Sand muhly	0.00	0.05	0.00	0.00	0.15	0.80
Alkali sacaton	0.00	0.10	0.00	0.00	0.30	0.60
Sand dropseed	0.00	0.05	0.00	0.00	0.10	0.85
Needle-and-thread	0.00	0.05	0.00	0.00	0.20	0.75
Leatherweed croton	0.00	0.00	0.00	0.00	0.15	0.85

Table B6 provides initial values for nitrogen (N) concentrations in plant tissues. The value in a particular tissue may vary from these values at any point in a simulation for either of two reasons. First, values may exceed the values shown here because of “luxury consumption” (i.e., the amount of N contained in the water absorbed by the plant may be sufficient to exceed these matrix values). Secondly, values may be less than the matrix values in some tissues because of internal transport of N from one tissue type to another during periods of green-out or rapid growth. The lower boundary for these concentrations is the maintenance levels (i.e., the concentration at which that particular tissue can remain alive but not grow). Maintenance levels are provided in Table B6 and are arbitrarily set at 90 percent of the Table B6 levels.

Table B6. Plant N concentration.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Broom snakeweed	0.0110	0.0120	0.0160	0.0090	0.0175	0.0330	0.0080	0.0087	0.0120	0.0200	0.0330
Creosotebush	0.0100	0.0110	0.0060	0.0120	0.0160	0.0300	0.0085	0.0120	0.0120	0.0180	0.0300
Sacahuista	0.0105	0.0110	0.0150	0.0160	0.0170	0.0350	0.0090	0.0100	0.0120	0.0130	0.0340
Yucca	0.0100	0.0105	0.0140	0.0150	0.0160	0.0400	0.0060	0.0080	0.0110	0.0120	0.0350
Purple threeawn	0.0085	0.0100	0.0110	0.0144	0.0150	0.0190	0.0100	0.0129	0.0100	0.0173	0.0210
Sideoats grama	0.0095	0.0105	0.0115	0.0150	0.0155	0.0210	0.0130	0.0140	0.0110	0.0160	0.0220
Black grama	0.0100	0.0110	0.0120	0.0154	0.0160	0.0200	0.0140	0.0145	0.0110	0.0183	0.0220
Blue grama	0.0101	0.0110	0.0120	0.0154	0.0160	0.0200	0.0140	0.0145	0.0110	0.0183	0.0220
Tobosa	0.0090	0.0100	0.0100	0.0120	0.0130	0.0200	0.0100	0.0110	0.0110	0.0140	0.0210
Sand muhly	0.0103	0.0110	0.0120	0.0150	0.0155	0.0200	0.0130	0.0145	0.0110	0.0160	0.0220
Alkali sacaton	0.0100	0.0110	0.0110	0.0140	0.0150	0.0200	0.0130	0.0140	0.0110	0.0160	0.0220
Sand dropseed	0.0105	0.0110	0.0120	0.0145	0.0150	0.0200	0.0125	0.0130	0.0110	0.0160	0.0220
Needle-and-thread	0.0100	0.0110	0.0120	0.0150	0.0155	0.0195	0.0135	0.0145	0.0110	0.0160	0.0210
Leatherweed croton	0.0090	0.0100	0.0110	0.0130	0.0190	0.0250	0.0120	0.0150	0.0110	0.0200	0.0270

Table B6 values are based on tissue N concentrations of composited aboveground tissue for the species, or most-similar species. Most of these values were taken from a large set of unpublished values from tissue samples analyzed in connection with a number of research projects. A limited amount of these data has been published (McLendon and Redente 1992, 1994; Redente et al. 1992; Paschke et al. 2000). Additional values were taken from the literature.

When available, values for separate tissue types were used. Tissue type concentrations (Table B7) were most often estimated from averages found in the literature (Gigon and Rorison 1972; Barth and Klemmedson 1982; Gay et al. 1982; Nicholas and McGinnes 1982; Risser and Parton 1982; Vogt et al. 1982; Heil and Diemont 1983; Stout et al. 1983; Uhl and Jordan 1984; McClaugherty et al. 1985; Nadelhoffer et al. 1985; Sears et al. 1986; Agren and Bosatta 1987; O'Connell 1988; McNeill and Wood 1990; Reichman and Smith 1991; Tilman and Wedin 1991).

Table B7. Maintenance levels.

Species	Min %	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Broom snakeweed	0.9000	0.0110	0.0120	0.0160	0.0090	0.0175	0.0330	0.0080	0.0087	0.0120	0.0200	0.0330
Creosotebush	0.9000	0.0100	0.0110	0.0060	0.0120	0.0160	0.0300	0.0085	0.0120	0.0120	0.0180	0.0300
Sacahuista	0.9000	0.0105	0.0110	0.0150	0.0160	0.0170	0.0350	0.0090	0.0100	0.0120	0.0130	0.0340
Yucca	0.9000	0.0100	0.105	0.0140	0.0150	0.0160	0.0400	0.0060	0.0080	0.0110	0.0120	0.0350
Purple threeawn	0.9000	0.0085	0.0100	0.0110	0.0144	0.0150	0.0190	0.0100	0.0129	0.0100	0.0173	0.0210
Sideoats grama	0.9000	0.0095	0.0105	0.0115	0.0150	0.0155	0.0210	0.0130	0.0140	0.0110	0.0160	0.0220
Black grama	0.9000	0.0100	0.0110	0.0120	0.0154	0.0160	0.0200	0.0140	0.0145	0.0110	0.0183	0.0220
Blue grama	0.9000	0.0101	0.0110	0.0120	0.0154	0.0160	0.0200	0.0140	0.0145	0.0110	0.0183	0.0220
Tobosa	0.9000	0.0090	0.0100	0.0100	0.0120	0.0130	0.0200	0.0100	0.0110	0.0110	0.0140	0.0210
Sand muhly	0.9000	0.0103	0.0110	0.0120	0.0150	0.0155	0.0200	0.0130	0.0145	0.0110	0.0160	0.0220
Alkali sacaton	0.9000	0.0100	0.0110	0.0110	0.0140	0.0150	0.0200	0.0130	0.0140	0.0110	0.0160	0.0220
Sand dropseed	0.9000	0.0105	0.0110	0.0120	0.0145	0.0150	0.0200	0.0125	0.0130	0.0110	0.0160	0.0220
Needle-and-thread	0.9000	0.0100	0.0110	0.0120	0.0150	0.0155	0.0195	0.0135	0.0145	0.0110	0.0160	0.0210
Leatherweed croton	0.9000	0.0090	0.0100	0.0110	0.0130	0.0190	0.0250	0.0120	0.0150	0.0110	0.0200	0.0270

Many species of plants resorb a portion of the N contained in tissue during senescence of the tissue and prior to death of that tissue. This resorbtion is especially common in tree leaves. Table B8 provides the maximum amounts of N within each tissue type that can be resorbed prior to tissue loss. The values are general estimates based on differences between N contents in green tissues and N contents in dead tissues.

Table B8 provides (1) the percentage of the total root biomass of each species that occurs at given depths (%) of soil profiles and (2) the maximum reported rooting depth for each species. A significant amount of root architecture data has been collected, both from the published literature and from our own studies. For each species, the amount of roots reported by depth is compared among all studies for which data are available for that species. These data are then used to calculate an average root biomass by depth values. Root biomass by depth percentages have been found to be relatively consistent across soil profiles for a given species, even where the depths of the soil profiles vary significantly.

The root percentages (Table B8) are multiplied by the estimated initial root biomass value for that species (Table B1) to arrive at an initial root biomass within each layer for each soil profile in the landscape. These are initial values only. As model simulation progresses, root architecture changes because of root growth and the location (depth) of belowground resources. Daily root production, based in part on the appropriate allocation matrix (Tables B1–B4), is added to the existing root biomass proportional to the amount of root biomass in each soil layer that supplied water to the plant on that particular day. The daily root production is based on two related concepts: (1) root growth occurs more in moist soil than in dry soil and (2) root growth in a soil layer is largely independent of soil moisture levels in other layers (Kramer 1969; Brown and Scott 1984; Huck 1984).

Maximum rooting depth sets the maximum depth to which a particular species can root. This value is the maximum found in the literature for that species, or the most-similar species. This limit is assumed to be primarily genetically determined, since the maximum reported depth was used. If the average maximum rooting depth was used, the depth would also be assumed to be strongly influenced by environmental factors.

Table B8. Nitrogen resorption.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Broom snakeweed	0.10	0.05	0.00	0.10	0.10	0.00
Creosotebush	0.10	0.05	0.00	0.10	0.30	0.00
Sacahuista	0.10	0.05	0.00	0.00	0.05	0.00
Yucca	0.10	0.05	0.00	0.00	0.05	0.00
Purple threeawn	0.10	0.05	0.00	0.10	0.10	0.00
Sideoats grama	0.10	0.05	0.00	0.10	0.20	0.00
Black grama	0.10	0.05	0.00	0.05	0.05	0.00
Blue grama	0.10	0.05	0.00	0.05	0.05	0.00
Tobosa	0.10	0.05	0.00	0.10	0.20	0.00
Sand muhly	0.10	0.05	0.00	0.05	0.05	0.00
Alkali sacaton	0.10	0.05	0.00	0.10	0.10	0.00
Sand dropseed	0.10	0.05	0.00	0.10	0.10	0.00
Needle-and-thread	0.10	0.05	0.00	0.05	0.05	0.00
Leatherweed croton	0.10	0.05	0.00	0.05	0.05	0.00

Table B9. Root architecture.

Species	Soil Layer												
	01	02	03	04	05	06	07	08	09	10	11	12	13
Broom snakeweed	0.02	0.04	0.08	0.08	0.10	0.15	0.20	0.15	0.08	0.04	0.03	0.02	0.01
Creosotebush	0.03	0.05	0.10	0.07	0.09	0.13	0.16	0.15	0.09	0.07	0.05	0.01	0.00
Sacahuista	0.02	0.04	0.08	0.08	0.10	0.15	0.20	0.15	0.08	0.04	0.03	0.02	0.01
Yucca	0.02	0.04	0.08	0.08	0.10	0.15	0.20	0.15	0.08	0.04	0.03	0.02	0.01
Purple threeawn	0.04	0.08	0.12	0.16	0.18	0.15	0.12	0.08	0.04	0.02	0.01	0.00	0.00
Sideoats grama	0.05	0.10	0.15	0.15	0.20	0.15	0.08	0.05	0.03	0.02	0.01	0.01	0.00
Black grama	0.05	0.15	0.15	0.15	0.20	0.10	0.10	0.06	0.03	0.01	0.00	0.00	0.00
Blue grama	0.05	0.15	0.15	0.15	0.20	0.12	0.10	0.05	0.02	0.01	0.00	0.00	0.00
Tobosa	0.05	0.25	0.10	0.10	0.15	0.10	0.10	0.08	0.04	0.02	0.01	0.00	0.00
Sand muhly	0.05	0.12	0.14	0.15	0.19	0.12	0.11	0.07	0.03	0.01	0.01	0.00	0.00
Alkali sacaton	0.04	0.06	0.10	0.15	0.20	0.20	0.12	0.06	0.03	0.02	0.01	0.01	0.00
Sand dropseed	0.04	0.06	0.10	0.15	0.20	0.20	0.12	0.06	0.03	0.02	0.01	0.01	0.00
Needle-and-thread	0.05	0.25	0.10	0.10	0.15	0.10	0.10	0.08	0.04	0.02	0.01	0.00	0.00
Leatherweed croton	0.06	0.10	0.16	0.15	0.10	0.20	0.12	0.06	0.04	0.01	0.00	0.00	0.00

Uptake capacity (Table B10) is the maximum amount of monthly water demand that can be supplied by the root system in one day. This amount was estimated to be 10 percent of the monthly demand.

Competitive efficiency is a measure of the relative efficiency of roots in water uptake. The fibrous root system of most short-grasses is used as the standard, and is assigned a competitive efficiency value of 1.0. Larger grasses, such as little bluestem, are assumed to have larger roots than shortgrasses. The larger roots of midgrasses are assumed to have a slightly lower efficiency for water uptake than the smaller roots of the shortgrasses. The larger roots of trees are assumed to be significantly less efficient, on a per gram basis, of water uptake than the smaller, fibrous roots of grasses. These relationships are based on the concept that water intake by roots is partly dependent on the roots' surface area.

The physiological matrix (Table B11) provides the data used in the model to determine in which months various plant functions occur. Data sources were Gould (1975) for most of the grasses and Correll and Johnston (1970) for most of the non-grasses. Green-out and dormancy values were based on the authors' personal estimates.

Table B12 provides values for (1) conversions between dry weight and wet weight, (2) amount of moisture intercepted by the canopy of each species, and (3) conversions between basal area and trunk biomass. These calculations are required for various calculations used in the simulations.

Table B10. Root uptake and biomass adjustment based on competitive efficiency.

Species	Uptake Capacity	Biomass Adjustment
Broom snakeweed	0.200	0.750
Creosotebush	0.200	0.600
Sacahuista	0.200	0.800
Yucca	0.200	0.750
Purple threeawn	0.200	1.000
Sideoats grama	0.200	0.900
Black grama	0.200	1.000
Blue grama	0.200	1.000
Tobosa	0.200	0.900
Sand muhly	0.200	1.000
Alkali sacaton	0.200	0.950
Sand dropseed	0.200	1.000
Needle-and-thread	0.200	1.000
Leatherweed croton	0.200	0.750

Table B11. Physiological response months.

Species	Green-out	Seed-	Sprout	Seed-	Set	Dormancy
Broom snakeweed	3	4,	9	7,	9	12
Creosotebush	3	3,	9	7,	9	12
Sacahuista	1	4,	8	6,	8	1
Yucca	1	4,	8	6,	8	1
Purple threeawn	2	3,	9	7,	9	12
Sideoats grama	3	4,	9	6,	9	11
Black grama	3	4,	8	8,	9	12
Blue grama	3	3,	8	7,	9	12
Tobosa	3	4,	9	7,	8	11
Sand muhly	3	4,	9	7,	9	12
Alkali sacaton	3	4,	9	7,	9	12
Sand dropseed	3	4,	9	7,	9	11
Needle-and-thread	10	10,	6	2,	5	6
Leatherweed croton	2	3,	9	4	8	11

Table B12. Biomass conversion constants.

Species	Dry wt/ Wet wt	Moisture Interception/ g biomass	Basal cover/ Trunk biomass
Broom snakeweed	0.28	0.008710	20.0
Creosotebush	0.50	0.008000	40.0
Sacahuista	0.49	0.009000	30.0
Yucca	0.45	0.008900	30.0
Purple threeawn	0.39	0.007000	30.0
Sideoats grama	0.28	0.008500	25.0
Black grama	0.50	0.008240	30.0
Blue grama	0.50	0.008270	20.0
Tobosa	0.40	0.008900	20.0
Sand muhly	0.40	0.008200	30.0
Alkali sacaton	0.37	0.008800	20.0
Sand dropseed	0.35	0.008200	40.0
Needle-and-thread	0.35	0.007500	30.0
Leatherweed croton	0.18	0.005000	40.0

Table B13 provides four sets of numbers that are used by the model to calculate water requirements of the plants. Green-out water use is the amount of water used to change from dry weight to wet weight. It is 1.00 - dry weight (Table B12). Maintenance is the amount of water required to support 1 g of old-growth biomass for 1 month. Old-growth biomass is that amount of live biomass produced in previous years. New biomass maintenance is the amount of water required to sustain 1 g of new-growth biomass for 1 month, in months where no new growth takes place. If this amount of water is not available, a proportional amount of new-growth tissue is converted to standing dead biomass (i.e., drought loss). The maintenance water-use values are estimates. Water to production is the amount of water (kilograms) required to produce 1 g of new biomass.

Table B13. Water use factors.

Species	Maintenance (mm/g bio/mo)	New biomass maintenance	Water to production (kg)	Green-out water use
Broom snakeweed	0.0000083	0.04	2.38	0.72
Creosotebush	0.0000080	0.04	3.51	0.50
Sacahuista	0.0000100	0.04	2.50	0.51
Yucca	0.0000090	0.04	3.00	0.55
Purple threeawn	0.0000124	0.04	1.05	0.61
Sideoats grama	0.0000150	0.05	1.09	0.72
Black grama	0.0000100	0.04	0.98	0.50
Blue grama	0.0000175	0.05	0.75	0.50
Tobosa	0.0000150	0.05	1.00	0.60
Sand muhly	0.0000120	0.05	0.92	0.60
Alkali sacaton	0.0000160	0.05	1.07	0.63
Sand dropseed	0.0000160	0.05	0.98	0.65
Needle-and-thread	0.0000200	0.06	1.52	0.65
Leatherweed croton	0.0000250	0.08	0.87	0.82

Maximum growth rate (shown in Table B14) is a productivity value of the estimated increase in aboveground biomass that could occur in 1 month under ideal conditions. A value of 1.00 means the biomass doubles each month. The growth rate value is multiplied by the amount of leaf-equivalent photosynthetically active biomass (Table B16) to determine potential monthly production. For potential monthly production to be achieved, sufficient water, nutrients, and sunlight have to be available to the species to achieve this production level. If any of these factors are limiting, potential monthly production is reduced proportionally. The amount of production actually achieved is then allocated according to the appropriate allocation matrix (Tables B2–B5).

The highest productivity rates are assigned to annuals, followed by herbaceous perennials, and then woody species. The rates were estimated based on the literature. Values reported in the literature for similar grass species range from 0.87 to 4.74 (Lissner et al. 1999; Fernandez and Reynolds 2000).

Table B14. Growth rate factors.

Species	Max growth rate
Broom snakeweed	0.80
Creosotebush	0.60
Sacahuista	0.20
Yucca	0.15
Purple threeawn	1.10
Sideoats grama	1.20
Black grama	1.10
Blue grama	1.00
Tobosa	1.50
Sand muhly	1.00
Alkali sacaton	1.25
Sand dropseed	1.05
Needle-and-thread	1.20
Leatherweed croton	1.50

The potential growth rates in Table B14 are the estimates for ideal conditions. One limiting factor is temperature. Warm-season species are most productive during the warmer part of the year, and cool-season species are more productive during cooler times. Table B15 provides a monthly growth curve for each species. The monthly growth rate value for the specific month is multiplied by the potential growth rate (Table B14) to determine the potential growth rate for that particular month. This is still a potential growth rate. It may be reduced because of water, nutrient, or sunlight limitations.

Photosynthesis occurs only in the leaves in some plants. In other species, limited photosynthesis can occur in other parts, such as stems. Table B16 provides the values used to calculate total photosynthetically active biomass for a species. A value of 1.00 is assigned to leaves, which is an assumption that leaves are the most productive part of the plant. Values less than 1.00 are assigned to the other plant parts. These values are estimates of the relative (compared with leaves) photosynthetic rate of each of these parts.

To determine total potential production at each time step (day) in the model, the biomass of each plant part is multiplied by the respective value in Table B16, and then the product is multiplied times the daily potential growth rate (Table B14 value divided by 30, adjusted for month of the year).

Table B15. Monthly maximum growth rates.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Broom snakeweed	0.00	0.00	0.60	0.90	1.00	1.00	1.00	1.00	0.90	0.60	0.20	0.00
Creosotebush	0.10	0.10	0.40	0.90	1.00	1.00	1.00	1.00	1.00	0.70	0.40	0.20
Sacahuista	0.10	0.10	0.40	0.90	1.00	1.00	1.00	1.00	0.90	0.70	0.40	0.20
Yucca	0.10	0.10	0.40	0.90	1.00	1.00	1.00	1.00	0.90	0.70	0.30	0.20
Purple threeawn	0.00	0.10	0.50	0.95	1.00	1.00	1.00	1.00	0.90	0.40	0.10	0.05
Sideoats grama	0.00	0.00	0.30	0.60	1.00	1.00	1.00	1.00	0.90	0.40	0.10	0.00
Black grama	0.00	0.05	0.40	0.90	1.00	1.00	1.00	1.00	0.90	0.50	0.20	0.05
Blue grama	0.00	0.05	0.70	0.95	1.00	1.00	1.00	0.80	0.80	0.50	0.20	0.00
Tobosa	0.00	0.05	0.50	0.90	1.00	1.00	1.00	1.00	1.00	0.70	0.20	0.00
Sand muhly	0.00	0.00	0.40	0.85	1.00	1.00	1.00	1.00	0.80	0.50	0.10	0.00
Alkali sacaton	0.05	0.10	0.40	0.80	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.10
Sand dropseed	0.00	0.00	0.30	0.80	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Needle-and-thread	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00	0.30	0.70	1.00	1.00
Leatherweed croton	0.10	0.10	0.40	0.80	1.00	1.00	1.00	1.00	0.90	0.40	0.20	0.10

Table B16. Plant part productivity.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Broom snakeweed	0.0	0.0	0.1	0.2	1.0	0.0
Creosotebush	0.0	0.0	0.0	0.1	1.0	0.0
Sacahuista	0.0	0.0	0.1	0.2	1.0	0.0
Yucca	0.0	0.0	0.1	0.2	1.0	0.0
Purple threeawn	0.0	0.0	0.0	0.3	1.0	0.0
Sideoats grama	0.0	0.0	0.1	0.3	1.0	0.0
Black grama	0.0	0.0	0.2	0.4	1.0	0.0
Blue grama	0.0	0.0	0.1	0.3	1.0	0.0
Tobosa	0.0	0.0	0.2	0.3	1.0	0.0
Sand muhly	0.0	0.0	0.0	0.3	1.0	0.0
Alkali sacaton	0.0	0.0	0.1	0.2	1.0	0.0
Sand dropseed	0.0	0.0	0.0	0.3	1.0	0.0
Needle-and-thread	0.0	0.0	0.0	0.4	1.0	0.0
Leatherweed croton	0.0	0.0	0.0	0.3	1.0	0.0

Green-out (regrowth) occurs following dormancy or severe defoliation. Green-out is triggered by cessation of the factor that caused defoliation (e.g., winter, fire, heavy grazing, trampling). Under these conditions, regrowth is initially fueled by translocation of stored nonstructural carbohydrates. Therefore, the biomass of the plant parts temporarily decreases where these carbohydrates were stored. In effect, the stored carbohydrates are converted to new tissue.

Table B17 specifies where these reserves are stored and how much is available for regrowth. A value of 1.00 indicates that an amount of new growth equal to the existing biomass of that plant part can be produced in 1 month. A value of 0.50 indicates that an amount of new growth equal to half of the existing biomass of that plant part can be produced in 1 month. In all cases, the given value does not mean that the existing biomass of the plant part is actually reduced by this amount, only that this is the potential new growth that can be generated from this existing biomass. The physiological process that occurs is that a given mass of carbohydrates are withdrawn from the stored reserves, used to produce the new leaf tissue, and most of these reserves are replaced from the production of photosynthates from the new leaves (Smith 1962; Garza 1994). The values in Table B17 simply indicate a net 1-month production rate.

Table B17. Green-out plant part productivity factor.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Broom snakeweed	0.1	0.0	0.3	0.2	1.0	0.0
Creosotebush	0.0	0.0	0.0	0.6	1.0	0.0
Sacahuista	0.2	0.0	0.5	0.5	1.0	0.0
Yucca	0.2	0.0	0.3	0.5	1.0	0.0
Purple threeawn	0.2	0.0	0.5	0.5	1.0	0.0
Sideoats grama	0.3	0.0	0.6	0.5	1.0	0.0
Black grama	0.1	0.0	0.2	0.5	1.0	0.0
Blue grama	0.3	0.0	0.6	0.5	1.0	0.0
Tobosa	0.4	0.0	0.7	0.5	1.0	0.0
Sand muhly	0.3	0.0	0.5	0.5	1.0	0.0
Alkali sacaton	0.4	0.0	0.6	0.5	1.0	0.0
Sand dropseed	0.3	0.0	0.5	0.5	1.0	0.0
Needle-and-thread	0.3	0.0	0.5	0.5	1.0	0.0
Leatherweed croton	0.2	0.0	0.4	0.4	1.0	0.0

Shading generally reduces the productivity of a shaded species, provided that the reduction in light intensity is sufficient. Commonly, no shading effect occurs initially, as the shading species begins to grow, because the shading species has insufficient canopy development to significantly reduce the intensity of the sunlight. As the biomass of the shading species increases, the canopy coverage increases and the light intensity under the canopy decreases. In some cases, some shading is actually beneficial to the shaded species because the reduced sunlight results in lower temperatures and therefore in lower transpirational water loss.

Shading is considered to be linear in the model. The shading effect on the shaded species is constant, and this effect increases linearly as the leaf biomass of the shading species increases. The values in Table B18 define the intensity of this effect. A value of 0.20 indicates that the potential growth (grams of new biomass) of the shaded species is reduced by a 0.20 percentage multiplied by 1 percent of the leaf biomass of the shading species. For example, for 500 g of juniper leaves, potential growth of buffalograss would be reduced by 0.5 percent (500 x 0.1 x 0.01).

Table B19 provides four physiological control factors that are used by the model to (1) keep above- and belowground biomass within reasonable limits and (2) provide for seedling development.

Table B18. Light competition factor (shading).

Shading Species	Shaded Species													
	Broom Snkwd	Creos Bush	Saca-Huista	Yucca	Red ThrAn	SdOats Grama	Black Grama	Blue Grama	Tobosa	Sand Muhly	Alkali Sacatn	Sand DrpSd	Needle Thrd	LW Croton
Broom snakeweed	0.0000	0.1000	0.1000	0.0000	0.0000	0.0500	0.0500	0.0000	0.5000	0.0000	0.1000	0.0000	0.0000	0.0000
Creosotebush	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3000	0.0000	0.1000	0.0000	0.0000	0.0000
Sacahuista	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Yucca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.0000	0.0000	0.0000	0.0000	0.0000
Purple threeawn	0.1000	0.1000	0.2000	0.0000	0.0000	0.2000	0.1000	0.0000	0.5000	0.0500	0.2000	0.0500	0.0000	0.0500
Sideoats grama	0.0000	0.0500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000
Black grama	0.0000	0.0500	0.1000	0.0000	0.0000	0.2000	0.0000	0.0000	0.2000	0.0000	0.0500	0.0000	0.0000	0.0500
Blue grama	0.0000	0.1000	0.2000	0.0000	0.0000	0.2000	0.0000	0.0000	0.2000	0.0000	0.0500	0.0000	0.0000	0.0500
Tobosa	0.0000	0.0500	0.0500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sand muhly	0.1000	0.1000	0.2000	0.0000	0.0000	0.2000	0.0500	0.0000	0.3000	0.0000	0.0500	0.0000	0.0000	0.0500
Alkali sacaton	0.0000	0.0000	0.0000	0.0000	0.0000	0.0500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sand dropseed	0.0000	0.0500	0.2000	0.0000	0.0000	0.2000	0.0500	0.0000	0.2000	0.0000	0.0500	0.0000	0.0000	0.0500
Needle-and-thread	0.1000	0.0500	0.1000	0.0000	0.0000	0.2000	0.0500	0.0000	0.4000	0.0500	0.1000	0.0500	0.0000	0.1000
Leatherweed croton	0.1000	0.1000	0.3000	0.0000	0.0000	0.2000	0.1000	0.0000	0.3000	0.0500	0.2000	0.1000	0.1000	0.0000

Table B19. Physiological control constraints.

Species	Growing season max root:shoot	Growing season green-out shoot:root	Max 1-mo seed germination	Max 1st-mo seedling growth
Broom snakeweed	1.9	0.2630	0.480	30.0
Creosotebush	1.3	0.3790	0.400	15.0
Sacahuista	4.9	0.1090	0.600	20.0
Yucca	4.9	0.1090	0.800	10.0
Purple threeawn	16.0	0.0490	0.350	40.0
Sideoats grama	0.7	0.9500	0.650	30.0
Black grama	3.3	0.1500	0.080	30.0
Blue grama	8.7	0.0730	0.340	40.0
Tobosa	0.3	0.1000	0.450	30.0
Sand muhly	2.4	0.0854	0.070	30.0
Alkali sacaton	6.8	0.0990	0.800	30.0
Sand dropseed	6.8	0.0990	0.400	40.0
Needle-and-thread	0.9	0.0500	0.130	30.0
Leatherweed croton	0.7	0.2720	0.700	50.0

The growing-season maximum root:shoot ratio value is used to prevent an imbalance occurring between above- and belowground biomass. If the root:shoot ratio exceeds this value, no growth allocation to roots takes place that month. No growth allows aboveground biomass to increase in relation to root biomass. The value for each species is set at twice the cumulative root:shoot ratio value (Table B2) for that species.

The growing-season green-out shoot:root ratio has a similar function, but it provides for a rapid readjustment between above- and belowground biomass. This readjustment can become necessary when a stressor (e.g., grazing, fire, mowing) causes a sudden removal of aboveground biomass. The growing season green-out shoot:root ratio is the trigger mechanism between green-out month and winter dormancy (Table B11). If the shoot:root ratio becomes less than the determined ratio, green-out is triggered. The value for each species equals half of the inverse of the maximum root:shoot ratio.

Maximum 1-month seed germination is the proportion of the seed bank for a particular species that can germinate in any single month of the seed germination months (Table B11). Most of the values were taken from, or estimated from Vories (1981), Fulbright et al. (1982), and Redente et al. (1982).

Maximum first-month seedling growth determines the maximum amount of biomass seedlings of each species can produce in the month of germination. The value in Table B19 is multiplied by the biomass of seeds of the respective species that germinate in that month (i.e., biomass in seed bank x maximum 1-month germination value). These values are estimates based on conceptual models of the relationships between 1-month-old seedling weights and the weight of the seed that produced the seedling.

Table B20 provides the values for the model to calculate how much of each plant part component for each species dies at the end of each growing season. All (1.00) tissue of all parts of annuals dies each year. For most herbaceous perennials, 100 percent of the leaves and stems die at the end of the growing season. Shrubs lose their leaves at the end of the growing season. Data used to calculate root survival were taken from Weaver (1954).

The purpose of the matrix shown as Table B21 is to designate into which pool dead material from each plant part is initially placed. A designation of -1 places the dead material into the soil organic matter of the layer in which the material existed at the time of death. A designation of 0 places the material in surface litter, a value of 7 places the material in the standing dead stems compartment, and a value of 8 places the material into standing dead leaves.

Table B20. End of growing season dieback.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Broom snakeweed	0.10	0.20	0.10	0.90	1.00	1.00
Creosotebush	0.05	0.10	0.02	0.10	0.50	1.00
Sacahuista	0.05	0.10	0.05	0.20	0.30	1.00
Yucca	0.05	0.10	0.05	0.20	0.20	1.00
Purple threeawn	0.10	0.20	0.10	1.00	1.00	1.00
Sideoats grama	0.05	0.10	0.05	1.00	1.00	1.00
Black grama	0.06	0.20	0.05	0.60	1.00	1.00
Blue grama	0.05	0.10	0.05	1.00	1.00	1.00
Tobosa	0.05	0.10	0.05	0.90	1.00	1.00
Sand muhly	0.05	0.10	0.05	1.00	1.00	1.00
Alkali sacaton	0.05	0.10	0.05	0.80	1.00	1.00
Sand dropseed	0.10	0.20	0.05	1.00	1.00	1.00
Needle-and-thread	0.05	0.10	0.05	1.00	1.00	1.00
Leatherweed croton	0.50	0.60	0.50	0.90	0.90	1.00

Table B21. Dieback fate.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Broom snakeweed	-1	-1	0	7	8	0
Creosotebush	-1	-1	0	7	8	0
Sacahuista	-1	-1	0	7	8	0
Yucca	-1	-1	0	7	8	0
Purple threeawn	-1	-1	0	7	8	0
Sideoats grama	-1	-1	0	7	8	0
Black grama	-1	-1	0	7	8	0
Blue grama	-1	-1	0	7	8	0
Tobosa	-1	-1	0	7	8	0
Sand muhly	-1	-1	0	7	8	0
Alkali sacaton	-1	-1	0	7	8	0
Sand dropseed	-1	-1	0	7	8	0
Needle-and-thread	-1	-1	0	7	8	0
Leatherweed croton	-1	-1	0	7	8	0

Table B22 designates how much of the biomass of each plant part of each species is lost in a moderate fire event (i.e., a relatively cool fire). A moderate fire event is defined as one in which the fuel load is 200 g/m^2 (1784 lb/ac). The fuel load for this calculation is defined as the sum of the litter plus the nontrunk aboveground biomass of all herbaceous species.

The actual effectiveness of the fire (i.e., amount of biomass removed) is proportional to the calculated fuel load. At values below 200 g/m^2, no biomass is removed. At these light fuel loads, it is assumed that the fire does not carry through the plot. At 800 g/m^2 of fuel and higher, a crown fire is simulated, in which 90 percent of aboveground biomass is removed. Between 200 and 800 g/m^2, removal is proportional to the difference between 200 and 800. The 90 percent value is used to account for intra-plot heterogeneity (i.e., it is assumed that 10 percent of a plot will remain unburned because of spatial variations in the fuel load). The fuel load threshold values used (200 and 800 g/m^2) are typical values for cool and hot fires, respectively, from central and north Texas (Scifres 1980).

Table B22. Plant part losses to fire events.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Broom snakeweed	0.00	0.00	0.60	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.60
Creosotebush	0.00	0.00	0.70	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.60
Sacahuista	0.00	0.00	0.40	0.50	0.50	0.50	1.00	1.00	0.00	1.00	0.60
Yucca	0.00	0.00	0.40	0.50	0.50	0.50	1.00	1.00	0.00	1.00	0.60
Purple threeawn	0.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.60
Sideoats grama	0.10	0.00	0.30	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.60
Black grama	0.00	0.00	0.40	0.90	1.00	1.00	1.00	1.00	0.00	1.00	0.60
Blue grama	0.00	0.00	0.10	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.60
Tobosa	0.00	0.00	0.30	0.90	1.00	1.00	1.00	1.00	0.00	1.00	0.60
Sand muhly	0.00	0.00	0.30	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.60
Alkali sacaton	0.00	0.00	0.30	0.90	0.90	0.90	1.00	1.00	0.00	1.00	0.60
Sand dropseed	0.00	0.00	0.30	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.60
Needle-and-thread	0.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.60
Leatherweed croton	0.00	0.00	0.80	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.60

The effectiveness of a material in contributing to the fuel load depends on a number of factors, including (1) size of the material, (2) moisture content, (3) compaction, and (4) chemical composition (e.g., volatile oil content). Table B23 provides a measure of these factors in adjusting the effect of the fuel loads calculated using Table B21.

In Table B23, a value of 1.00 is typical of green fine fuel, such as grass leaves. A value of 1.50 is typical of dry fine fuel, such as dead grass leaves. Woody or particularly lush herbaceous materials have values of less than 1.00. Materials containing volatile oils have values of 2.00 or greater, depending on moisture content.

The values in this matrix (Table B24) represent estimates of the physical impact of a single trampling event. A value of 0.50, for example, indicates that 50 percent of the biomass of that plant part is removed and transferred to the litter compartment. This matrix does not address whether or not the plant is killed by the trampling event. Survivability is simulated by the response of the plant to the tissue loss over time.

Table B23. Fuel combustibility factor.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Broom snakeweed	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Creosotebush	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Sacahuista	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Yucca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
Purple threeawn	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Sideoats grama	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Black grama	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Blue grama	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Tobosa	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Sand muhly	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Alkali sacaton	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Sand dropseed	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Needle-and-thread	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Leatherweed croton	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00

Table B24. Plant loss to trampling or a single vehicle pass.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves
Broom snakeweed	0.00	0.00	0.80	1.00	1.00	1.00	1.00	1.00
Creosotebush	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
Sacahuista	0.00	0.00	0.50	1.00	0.90	1.00	1.00	1.00
Yucca	0.00	0.00	0.70	1.00	0.80	1.00	1.00	0.90
Purple threeawn	0.00	0.00	0.50	1.00	0.90	1.00	1.00	0.90
Sideoats grama	0.00	0.00	0.30	1.00	0.80	1.00	1.00	0.80
Black grama	0.00	0.00	0.60	0.80	0.80	1.00	1.00	0.80
Blue grama	0.00	0.00	0.40	0.90	0.80	1.00	1.00	0.50
Tobosa	0.00	0.00	0.20	0.90	0.60	1.00	1.00	0.40
Sand muhly	0.00	0.00	0.60	0.90	0.90	1.00	1.00	0.80
Alkali sacaton	0.00	0.00	0.40	0.80	0.80	1.00	1.00	0.60
Sand dropseed	0.00	0.00	0.70	0.90	0.80	1.00	1.00	0.80
Needle-and-thread	0.00	0.00	0.50	1.00	0.90	1.00	1.00	0.90
Leatherweed croton	0.00	0.00	0.70	0.80	0.80	1.00	1.00	0.90

Herbivory is simulated in the model as a species-specific and a plant part-specific process. Each species of herbivore selects various plant species, based on the preference of that herbivore and the availability of the plant species. In addition, each herbivore also selects individual plant parts of individual species based on preference and availability.

The first number of each pair in Table B25 is the relative preference value for that plant part of that species for a specific herbivore. Cattle prefer grasses and rabbits prefer forbs. Therefore, grasses have higher preference values for cattle than they do for rabbits. However, cattle prefer some grasses over others. Grama grasses are more preferred than are tobosa and needle-and-thread, provided each of these species has new growth available.

In addition to species preferences, this matrix also allows for grazing characteristics to be simulated. Cattle graze by wrapping their tongues around the plant and pulling off the material. Therefore, they are not particularly selective as to plant part. In contrast, rabbits "nip" or bite off small portions of the plants, and can be very selective as to plant parts and plant species. In Table B25, sideoats grama stems and leaves have the same preference value for cattle. Cattle have difficulty selecting only leaves because of their grazing habit. For rabbits, however, the stems of sand dropseed have a lower preference value than leaves. This lower value reflects the ability of rabbits to strip the leaves off the stems.

Table B25. Herbivore preference and competition (P, C).

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Insects											
Broom snakeweed	0,2	0,2	9,1	6,1	5,1	5,1	0,1	6,1	0,3	3,1	0,2
Creosotebush	0,2	0,2	0,1	0,1	6,1	8,1	0,1	7,1	0,3	4,1	0,2
Sacahuista	0,2	0,2	5,1	5,1	4,1	8,1	0,1	5,1	0,3	5,1	0,2
Yucca	0,2	0,2	5,1	6,1	5,1	3,1	0,1	6,1	0,3	5,1	0,2
Purple threeawn	0,2	0,2	5,1	4,1	3,1	5,1	5,1	4,1	0,3	2,1	0,2
Sideoats grama	0,2	0,2	4,1	2,1	1,1	3,1	3,1	2,1	0,3	1,1	0,2
Black grama	0,2	0,2	4,1	3,1	2,1	4,1	4,1	3,1	0,3	1,1	0,2
Blue grama	0,2	0,2	4,1	2,1	1,1	3,1	4,1	2,1	0,3	1,1	0,2
Tobosa	0,2	0,2	5,1	3,1	2,1	4,1	5,1	3,1	0,3	2,1	0,2
Sand muhly	0,2	0,2	4,1	3,1	2,1	4,1	4,1	3,1	0,3	1,1	0,2
Alkali sacaton	0,2	0,2	5,1	3,1	2,1	4,1	5,1	3,1	0,3	2,1	0,2
Sand dropseed	0,2	0,2	4,1	3,1	2,1	4,1	4,1	3,1	0,3	1,1	0,2
Needle-and-thread	0,2	0,2	4,1	3,1	2,1	4,1	4,1	3,1	0,3	1,1	0,2
Leatherweed croton	0,2	0,2	3,1	2,1	1,1	2,1	4,1	2,1	0,3	1,1	0,2
Rabbits											
Broom snakeweed	0,1	0,1	9,2	10,2	7,2	8,2	11,2	10,2	0,2	5,2	0,1
Creosotebush	0,1	0,1	11,2	10,2	8,2	7,3	11,2	11,2	0,2	6,2	8,1
Sacahuista	0,1	0,1	10,2	10,2	9,2	6,3	11,2	10,2	0,2	5,2	0,1
Yucca	0,1	0,1	6,2	7,2	4,2	2,3	8,2	8,2	0,2	2,2	7,1
Purple threeawn	0,1	0,1	8,2	4,2	4,2	5,2	5,2	5,2	0,2	2,2	0,1
Sideoats grama	7,1	7,1	7,2	3,2	2,2	3,2	5,2	4,2	0,2	1,2	4,1
Black grama	0,1	0,1	7,2	3,2	3,2	4,2	4,2	3,2	0,2	1,2	0,1
Blue grama	0,1	0,1	7,2	3,2	3,2	3,2	4,2	3,2	0,2	1,2	0,1
Tobosa	7,1	7,1	8,2	4,2	3,2	3,2	7,2	6,2	0,2	2,2	0,1
Sand muhly	0,1	0,1	8,2	4,2	3,2	4,2	6,2	5,2	0,2	2,2	0,1
Alkali sacaton	0,1	0,1	6,2	4,2	3,2	4,3	6,2	5,2	0,2	2,2	0,1
Sand dropseed	0,1	0,1	7,2	4,2	2,2	4,2	5,2	4,2	0,2	1,2	0,1
Needle-and-thread	0,1	0,1	7,2	4,2	3,2	5,2	6,2	5,2	0,2	1,2	0,1
Leatherweed croton	7,1	7,1	8,2	3,2	1,2	2,2	5,2	4,2	0,2	1,2	0,1

Table B25 (Cont'd). Herbivore preference and competition (P, C).

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Cattle											
Broom snakeweed	0,3	0,3	0,3	11,3	10,3	10,3	13,3	13,3	0,1	9,3	0,3
Creosotebush	0,3	0,3	0,3	12,3	11,3	12,2	0,3	12,3	0,1	10,3	0,3
Sacahuista	0,3	0,3	12,3	9,3	8,3	6,2	13,3	13,3	0,1	8,3	0,3
Yucca	0,3	0,3	11,3	10,3	9,3	2,3	0,3	12,3	0,1	9,3	7,3
Purple threeawn	0,3	0,3	7,3	5,3	5,3	5,3	6,3	6,3	0,1	4,3	0,3
Sideoats grama	0,3	0,3	3,3	1,3	1,3	1,3	2,3	2,3	0,1	1,3	3,3
Black grama	0,3	0,3	3,3	1,3	1,3	1,3	1,3	1,3	0,1	1,3	3,3
Blue grama	0,3	0,3	3,3	1,3	1,3	1,3	1,3	1,3	0,1	1,3	4,3
Tobosa	0,3	0,3	6,3	4,3	4,3	4,3	5,3	5,3	0,1	2,3	3,3
Sand muhly	0,3	0,3	4,3	2,3	2,3	2,3	3,3	3,3	0,1	1,3	3,3
Alkali sacaton	0,3	0,3	5,3	3,3	3,3	3,2	4,3	4,3	0,1	2,3	3,3
Sand dropseed	0,3	0,3	4,3	2,3	2,3	2,3	3,3	3,3	0,1	1,3	3,3
Needle-and-thread	0,3	0,3	2,3	1,3	1,3	1,3	2,3	1,3	0,1	1,3	4,3
Leatherweed croton	0,3	0,3	8,3	6,3	6,3	6,3	7,3	7,3	0,1	4,3	3,3

The second number of each pair in TableB25 is the relative competition value for each plant part of each species for each herbivore. This value is used to determine which herbivore gets first choice of that plant part, when more than one herbivore attempts to select it and the amount is insufficient to supply both herbivores. In most cases, this value assumes that, if the material is limited, insects are most likely to acquire the limited resource, followed by rabbits, and finally cattle.

Another important aspect of determining herbivore diets is accessibility, which relates to how much of a particular plant part a herbivore could select if it wanted the plant part. A high value in the Table B25 matrix does not suggest that the herbivore would actually select that plant part. Selection is largely determined by preference (Table B24).

The accessibility value for blue grama leaves to cattle is 70. This indicates that cattle could access 70 percent of the leaves of blue grama. The value for rabbits is 100. Blue grama is a shortgrass. It produces some leaves that are very close to the ground. Cattle cannot access these leaves close to the ground because their tongue "wrapping" will not detach them from the stems. Rabbits, however, have smaller mouths than cattle and can select each of the leaves down to ground level.

Table B26. Herbivore accessibility.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
<u>Insects</u>											
Broom snakeweed	0	0	90	100	100	100	100	100	0	100	10
Creosotebush	0	0	100	100	100	100	100	100	0	100	60
Sacahuista	0	0	100	100	100	100	100	100	0	100	20
Yucca	0	0	100	100	100	100	100	100	0	100	50
Purple threeawn	0	0	50	100	100	100	100	100	0	100	20
Sideoats grama	0	0	50	100	100	100	100	100	0	100	60
Black grama	0	0	50	100	100	100	100	100	0	100	50
Blue grama	0	0	60	100	100	100	100	100	0	100	40
Tobosa	0	0	40	100	100	100	100	100	0	100	50
Sand muhly	0	0	50	100	100	100	100	100	0	100	40
Alkali sacaton	0	0	40	100	100	100	100	100	0	100	10
Sand dropseed	0	0	50	100	100	100	100	100	0	100	10
Needle-and-thread	0	0	50	100	100	100	100	100	0	100	20
Leatherweed croton	0	0	50	100	100	100	100	100	0	100	30
<u>Rabbits</u>											
Broom snakeweed	10	0	80	100	90	90	100	90	10	80	0
Creosotebush	10	0	100	70	60	50	70	60	10	80	20
Sacahuista	10	0	90	100	100	100	100	100	10	80	0
Yucca	10	0	100	90	100	90	90	100	10	80	40
Purple threeawn	0	0	60	100	100	90	100	100	5	80	10
Sideoats grama	20	0	100	100	100	90	100	100	10	80	10
Black grama	10	0	90	90	100	90	90	100	10	80	5
Blue grama	10	0	70	100	100	100	100	100	10	80	5
Tobosa	20	0	60	100	100	90	100	100	10	80	10
Sand muhly	10	0	100	100	100	90	100	100	10	80	5
Alkali sacaton	20	0	60	90	80	80	90	80	10	80	0
Sand dropseed	10	0	90	100	100	90	100	100	10	80	0
Needle-and-thread	0	0	60	100	100	90	100	100	5	80	5
Leatherweed croton	10	0	100	100	100	90	100	100	10	80	0

Figure B26 (Cont'd). Herbivore accessibility.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Cattle											
Broom snakeweed	0	0	0	70	70	80	70	70	0	50	0
Creosotebush	0	0	50	90	80	80	90	80	0	50	0
Sacahuista	10	0	70	90	80	100	90	80	0	50	0
Yucca	10	0	70	90	80	90	90	80	0	50	0
Purple threeawn	0	0	20	90	90	100	90	90	0	50	0
Sideoats grama	0	0	20	90	90	90	90	90	0	50	0
Black grama	0	0	30	90	90	100	90	90	0	50	0
Blue grama	0	0	10	90	70	100	90	70	0	50	0
Tobosa	0	0	20	90	80	100	90	90	0	50	0
Sand muhly	0	0	20	90	90	100	90	90	0	50	0
Alkali sacaton	0	0	10	70	70	90	70	70	0	50	0
Sand dropseed	0	0	30	90	90	100	90	90	0	50	0
Needle-and-thread	0	0	20	90	90	90	90	90	0	50	0
Leatherweed croton	0	0	70	90	90	90	90	90	0	50	0

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14. ABSTRACT

The Terrestrial Ecosystem Simulation Model (TerreSIM) is a computer simulation model designed to be a useful evaluation and planning tool for investigating ecological responses over time to a wide variety of natural and anthropogenic stressors on spatial scales ranging from small plots to large landscapes and watersheds. TerreSIM is the next generation of modeling efforts at MFG, Inc, built upon general principles of ecology. This document presents the results of an application of the TerreSIM model to a 94 km2 training area landscape in the north central part of Fort Bliss. Results of these simulations indicate that fire, cattle grazing, and military training all affect vegetation dynamics on this landscape, but that the relative importance of each factor is quite different. Model simulations indicate that the landscape can support moderate grazing by cattle and military training for at least 20 years, provided that at least average precipitation is received. TerreSIM provides the tool for Fort Bliss land managers to develop appropriate management options under changing climatic, pyric, and successional conditions.

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